U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB-284 297

Source Assessment Coal Storage Piles

Monsanto Research Corp, Dayton, Ohio

Prepared for

Industrial Environmental Research Lab -Cincinnati, Ohio

May 78

United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-78-004k
May 1978

Research and Development

PB 284 297

EPA

Source Assessment: Coal Storage Piles

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-78-004k		PB284297

4. TITLE AND SUBTITLE	5. REPORT DATE
SOURCE ASSESSMENT: COAL STORAGE PILES	May 1978 issuing date
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
T. R. Blackwood and R. A. Wachter	MRC-DA-504
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
Monsanto Research Corporation 1515 Nicholas Road Dayton, Ohio 45407	1BB610
	11. CONTRACT/GRANT NO.
	68-02-1874
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Industrial Environmental Research Lab-Cinn., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268	Task Final, 5/74-9/75
	14. SPONSORING AGENCY CODE
	EPA/600/12

15. SUPPLEMENTARY NOTES

IERL-Ci project lead for this report is John F. Martin, 513/684-4417

16. ABSTRACT

This report describes a study of atmospheric emissions from coal storage piles. Fugitive emissions of dust and gases are emitted from coal storage piles. The average emission factor for respirable particulate (<7 μm) is 6.4 mg/kg per annum; this factor describes the emission rate 95% of the time within 108%. From the distribution of coal piles, a representative pile was selected containing 95,000 metric tons of bituminous coal. The emission rate from this pile averages 19 mg/s or 610 kg/yr. In order to evaluate the potential environmental effect of coal storage piles, a severity factor was defined as the ratio of the maximum ground level concentration of an emission to the ambient air quality standard for criteria pollutants and to a modified threshold limit value for other pollutants. Severity factors for a representative coal storage pile are 0.025 and 1.0 when the emissions are treated as gross particulate and coal dust, respectively. The national emission burden from all coal storage piles is 0.00048% of total national particulate emissions. The amount of coal stored is increasing at the rate of 3.8% per year and this will result in a 25% increase in emissions in 1978 compared to 1972. Air pollution control techniques for coal storage piles have not been generally established and no future control techniques are presently under consideration.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Coal Dust Gases	Air Pollution Control Stationary Sources Source Severity Particulate	68A

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
RELEASE TO PUBLIC	UNCLASSIFIED	98
	20. SECURITY CLASS (This page)	22. PRICE
	UNCLASSIFIED	A05 - A01

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978— 757-140/6851

EPA-600/2-78-004k
May 1978

SOURCE ASSESSMENT: COAL STORAGE PILES

by

T. R. Blackwood and R. A. Wachter
Monsanto Research Corporation
1515 Nicholas Road
Dayton, Ohio 45407

Contract No. 68-02-1874
Program Element No. 1BB610

Project Officer

John F. Martin
Resource Extraction and Handling Division
Industrial Environmental Research Laboratory
Cincinnati, Ohio 45268

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

1a

DISCLAIMER

This report has been reviewed by the Industrial Environmental Research Laboratory-Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains an assessment of air emissions from coal storage piles. This study was conducted to provide sufficient information for EPA to ascertain the need for developing control technology for this source. Further information on this subject may be obtained from the Extraction Technology Branch, Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

PREFACE

The Industrial Environmental Research Laboratory (IERL) of the U.S. Environmental Protection Agency (EPA) has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Water Act and solid waste legislation. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. Approaches considered include: process modifications, feedstock modifications, add-on control devices, and complete process substitution. The scale of the control technology programs ranges from bench- to full-scale demonstration plants.

IERL has the responsibility for developing control technology for a large number (>500) of operations in the chemical and related industries. As in any technical program, the first step is to identify the unsolved problems. Each of the industries is to be examined in detail to determine if there is sufficient potential environmental risk to justify the development of control technology by IERL. This report contains the data necessary to make that decision for coal storage piles.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program entitled "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer for this series. This study of coal storage piles was initiated by IERL-Research Triangle Park in May 1974; Mr. David K. Oestreich served as EPA Project Leader. The project was transferred to the Resources Extraction and Handling Division, IERL-Cincinnati, in October 1975; Mr. John F. Martin served as EPA Project Leader through completion of the study.

ABSTRACT

This report describes a study of air pollutants emitted from coal storage piles. The potential environmental effect of this emission source is evaluated.

Coal storage piles are open sources of atmospheric emissions of fugitive dust and gaseous hydrocarbons. Of the criteria pollutants, carbon monoxide, hydrocarbons, and particle matter are emitted. Concentrations of carbon monoxide and hydrocarbons are three orders of magnitude below ambient air quality criteria at a distance of 50 meters from the pile. The average emission factor for respirable particulate (<7 μm) is 6.4 mg/kg per year.

From the distribution of coal piles, a representative pile was selected containing 95,000 metric tons of bituminous coal. The emission rate from this pile averages 19 mg/s or 610 kg/yr. In order to evaluate the potential environmental effect of coal storage piles, a source severity factor was defined as the ratio of the maximum ground level concentration of an emission to the ambient air quality standard for criteria pollutants and to a modified threshold limit value for other pollutants. Severity factors for a representative coal storage pile are 0.025 and 1.0 when the emissions are treated as gross particulate and coal dust, respectively.

The national emission burden from all coal storage piles is 0.00048% of total national particulate emissions. The amount of coal stored is increasing at the rate of 3.8% per year and this will result in a 25% increase in emissions in 1978 compared to 1972.

Air pollution control techniques for coal storage piles have not been generally established and no future control techniques are presently under consideration.

This report was submitted in partial fulfillment of Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period May 1974 to September 1975, and the work was completed as of July 1977.

CONTENTS

Foreword		iii
Preface		iv
Abstract		v
Figures		viii
Tables		ix
Abbreviations and Symbols		xi
Conversion Factors and Metric Prefixes		xiii
I	Introduction	1
II	Summary	2
III	Source Description	4
	A. Process Description	4
	1. Emission Sources	4
	2. Source Composition	5
	B. Factors Affecting Emissions	9
	C. Geographical Distribution of Coal Storage Piles	11
IV	Emissions	13
	A. Selected Pollutants	13
	B. Mass Emissions	15
	C. Representative Source	15
	D. Environmental Effects	17
	1. Ground Level Concentration	17
	2. Hazard Factor	18
	3. Source Severity	18
V	Control Technology	20
	A. State of the Art	20
	B. Future Considerations	20
VI	Growth and Nature of the Industry	22
	A. Present and Emerging Technology	22
	B. Coal Storage Trends	22
References		24
Appendices		
	A. Analysis of Sampling Results	27
	B. Factors Affecting Coal Storage Emissions	36
	C. Derivation of Surface Area from Height of Coal Piles	49

Preceding page blank

CONTENTS (continued)

Appendices (continued)

D. Sampling Equipment and Procedures 51
E. Computation of Combined Errors 62
F. Determination of Distance to Plant Boundary and Population Density for Representative Coal Storage Pile 64
G. Analysis of Coal Storage Piles for Polycyclic Organic Materials 65
H. Derivation of Source Severity Equations 67

Glossary 81

FIGURES

Number		Page
1	Map of P-E values for state climatic divisions	10
2	Distribution of coal piles	12
3	Distribution of quantity of coal stored versus P-E region	12
4	Area affected down to a severity of 0.1	19
A-1	March sampling arrangement, Runs C1 and C2	28
A-2	August sampling arrangement, Runs CS-3 and CS-5	28
D-1	Fugitive dust sampling worksheet	61

TABLES

Number		Page
1	Concentrations of Trace Metals in Coal and Coal Dust	7
2	Composite TLV of all the Elements in Coal Dust	8
3	Analysis of Grab Samples for Total Hydrocarbons, Methane, Carbon Monoxide and Sulfur (AS H_2S, SO_2 and RS)	14
4	State and National Emissions	16
5	Comparison of the Representative Coal Storage Pile to the Pile Selected for Sampling	17
6	Source Severity	19
A-1	Sampling Results - March and August 1974	30
A-2	Data for Calculation of the Constant (k)	33
A-3	X-ray Fluorescence Analysis of Samples from Filters	34
A-4	Particle Size Analyses	35
B-1	Sensitivity Analysis of Entrainment/Emission Rates Calculated Using Equation B-18 with Average, Minimum and Maximum Values for Wind Velocity, Bulk Density, P-E Index and Surface Area	47
C-1	Height of Coal Piles	50
D-1	Open Sources Sampling Guidelines	58
D-2	Placement of Samples Downwind of Obstructions	59
D-3	Fugitive Dust Sampler and Meteorological Data Log	60
F-1	Distance to Plant Boundary and Population Density for Representative Coal Storage Pile	64
G-1	Analysis of Coal Samples Extracted with Pentane for Selected Polycyclic Organic Materials (POM's) by Chemical Ionization Mass Spectroscopy	66

TABLES (continued)

Number		Page
H-1	Pollutant Severity Equations	68
H-2	Values of a for the Computation of σ_y	70
H-3	Values of the Constants used to Estimate Vertical Dispersion	70
H-4	Summary of National Ambient Air Quality Standards	76

ABBREVIATIONS AND SYMBOLS

a, ..., g, m, n	-- variable exponents and coefficients used in numerous mathematical manipulations
A, ..., G	-- stability classes; also used to designate reference distances for hi-volume samplers
A_L	-- leading angle at the base of a coal dust bed
A_R, B_R	-- substitution variables
B1, B2	-- particle size samples
C_i	-- concentration of the i-th chemical element
C, C'	-- local wind erosion climatic factor
C1, C2, CS-3, CS-5	-- valid hi-volume sampler runs
D	-- representative distance
d	-- distance across a field
D_o	-- annual days of operation of a facility storing coal
D_s	-- average days of supply of coal stored at a facility
E	-- potential average annual soil loss
E_N, E_{SO}, E_p, E_S, E_A	-- variables used by different authors to represent entrainment rate
exp	-- natural log base, e $\simeq$ 2.72
E_2, E_3, E_4	-- erodibility factor functions
F	-- hazard factor
F_c	-- total concentration of all i-th chemical elements in the dust
Fu	-- frictional velocity
G1, G2, ..., G12	-- gas sample numbers
H	-- height of a coal dust bed
h	-- height of emission
I	-- soil and knoll erodibility index
K, K'	-- surface and ridge roughness
K_1, ..., K_7	-- constants
L'	-- unsheltered distance across a field along the prevailing wind direction
M	-- moisture content
n	-- number of samples collected
N	-- number of chemical elements
P	-- monthly precipitation
P-E index	-- regional precipitation-evaporation level (as expressed by Thornthwaite (Reference 13)

ABBREVIATIONS AND SYMBOLS (continued)

ppm	-- parts per million
Q	-- emission rate
Q_f	-- final air flow rate
Q_i	-- initial air flow rate
S	-- source severity
s	-- surface area
SD	-- size distribution
S_0, ..., S_4	-- hi-volume sampler numbers
T	-- monthly mean temperature
t	-- "Student t" value for n - 1 degrees of freedom
T_c	-- weight of coal stored
T_i	-- TLV of the i-th chemical element
t_L	-- sampling time for which concentrations for longer periods are calculated
TLV	-- threshold limit value of a material
T_M	-- composite TLV of a compound
t_{max}	-- sampling time for which χ_{max} was determined
t_s	-- sampling time
u	-- arithmetic mean wind speed
u_{ave}	-- average wind speed
u_L	-- wind velocity at the midheight of a coal dust bed
V	-- volume of a coal dust bed
V'	-- vegetative cover
V_a	-- volume of air sampled
v, u, u_{ave}, v_F	-- variables used by different authors for wind speed or velocity
W	-- width of a coal dust bed
W_i	-- initial (tare) weight of filter
W_t	-- final weight of filter
$\underline{X}$	-- any average value
$\overline{X}$	-- arithmetic mean measure of any value, X
x, y, z	-- downwind coordinate distances
π	-- a constant approximately equal to 3.14
ρ_b	-- bulk density
σ	-- estimated population standard deviation
σ_y	-- standard deviation of plume dispersal in horizontal plane
σ_z	-- standard deviation of plume dispersal in vertical plane
χ	-- concentration
$\underline{\chi}_{max}$	-- maximum concentration
$\overline{\chi}$	-- mean ambient concentration

CONVERSION FACTORS AND METRIC PREFIXES[a]

CONVERSION FACTORS

To convert from	to	Multiply by
degree Celsium (°C)	degree Fahrenheit (°F)	$t_{°F} = 1.8t_{°C} + 32$
kilogram (kg)	grain (1/7,000 lb mass avoirdupois)	1.543×10^{4}
kilogram (kg)	pound (mass)	2.205
meter (m)	foot	3.281
meter (m)	inch	3.937×10^{1}
meter (m)	yard	1.094
meter^2 (m^2)	mile^2	3.861×10^{-7}
meter^3 (m^3)	foot^3	3.531×10^{1}
meter^3 (m^3)	inch^3	6.101×10^{4}
meter^3 (m^3)	liter	1.000×10^{-3}
meter^3 (m^3)	yard^3	1.308
metric ton	ton	1.102×10^{3}
pascal (Pa)	inch of water (60°F)	4.019×10^{-3}
pascal (Pa)	pound-force/inch^2 (psi)	1.450×10^{-4}
radian	degrees	5.730×10^{1}

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
kilo	k	10^{3}	1 kg = 1×10^{3} grams
centi	c	10^{-2}	1 cm = 1×10^{-2} meter
milli	m	10^{-3}	1 mm = 1×10^{-3} meter
micro	μ	10^{-6}	1 μm = 1×10^{-6} meter

[a] Metric Practice Guide. ASTM Designation E 380-74, American Society for Testing and Materials, Philadelphia, Pennsylvania, November 1974. 34 pp.

SECTION I

INTRODUCTION

Coal storage piles contribute fugitive emissions to the atmosphere in the form of coal dust. The severity or potential environmental risk of emissions from these piles and other open sources had been ranked relative to each other through the use of an impact factor. This factor is a measure of the local population density that is exposed to the maximum concentration of all emissions from coal storage piles relative to the hazardous nature of each emission. Although the impact factor was low for coal storage piles compared to other open sources, coal storage was investigated as a prototype for development of the logic and methods to be used in the future assessment of various other source types. It also served to test the consistency of the logic applied.

An analysis of coal storage piles was conducted to assess the distribution and character of emissions in greater detail than is available in the literature. The emphasis of the assessment has been to ascertain whether control technology development is required. The following data are compiled in this document:

- The number of coal storage piles
- Distribution of coal storage in the U.S.
- A documented emission factor
- The composition of emissions
- The hazard potential of emissions
- The factors which affect the emissions
- Total national emissions
- Contribution to state emissions burden
- A relative severity factor (used in comparing other source assessments)
- Type of control technology used and proposed
- Growth of coal storage piles

SECTION II

SUMMARY

Coal storage piles are open sources of atmospheric emissions of fugitive dust and gaseous hydrocarbons. The emission rate varies due to meteorological and topographical influences. Of the criteria pollutants, carbon monoxide, hydrocarbons, and particulate matter are emitted. The concentrations of carbon monoxide and hydrocarbons are three orders of magnitude below ambient air quality criteria at a distance of 50 m (164 ft) from the coal pile. Thus, a detailed analysis of the severity was not required. The respirable particulate matter (<7 μm) emitted is coal dust, which has a threshold limit value (TLV®) of 2 mg/m^3. These emissions were found to be affected by wind speed, surface area of the pile, coal density, and regional precipitation evaporation (P-E) index. However, a sensitivity analysis indicates that these parameters do not preclude the use of an average emission factor of 6.4 mg/kg (0.013 lb/ton) per annum. This factor describes the emission rate within 6.9 mg/kg (0.014 lb/ton) per annum, 95% of the time.

From a study of the distribution of coal piles, a representative coal pile was defined as containing 95,000 metric tons[a] (100,000 tons) of bituminous coal with an average pile height of 5.8 m (19 ft). It is located in a P-E region with an annual index of 91 (U.S. average) and an annual average wind speed of 4.5 m/s (10 mph). The emission rate from this pile averages 19 mg/s (0.15 lb/hr) or 610 kg/yr. The severity of the representative pile is 0.025 when the emissions are considered as gross particulate, and 1.0 when treated as coal dust. The population affected, above a severity of 0.1, is 58 persons.

The national emission burden from coal storage piles is 630 metric tons/yr (690 tons/yr) or 0.00048% of total national particulate emissions. No state has an emission burden from this source of greater than 0.0026% of the state's total particulate emissions.

---

[a] 1 metric ton = 10^6 grams - 2,205 pounds = 1.1 short tons (short tons are designated "tons" in this document); conversion factors and metric system prefixes are presented in the prefatory pages of this report.

In 1973, over 98 x 10^6 metric tons (108 x 10^6 tons) of coal was reportedly stockpiled at over 950 user sites located in 479 counties at coke plants, electric generating stations, and industrial boiler facilities. The amount of coal stored is increasing at the rate of 3.8% per year, mainly due to the construction of new coal-fired plants. This trend will result in an increase in emissions of 25% in 1978 compared to 1972.

Air pollution control techniques for coal storage have not been generally established and no future control techniques are presently under consideration.

SECTION III

SOURCE DESCRIPTION

A. PROCESS DESCRIPTION

1. Emission Sources

The term coal storage refers to over 98 x 10^6 metric tons of coal stockpiled at coke plants, electric generating stations, and industrial boilers (1-4). There are over 950 of these facilities reportedly using coal and maintaining coal storage piles. Coal mines do not stockpile coal because of safety hazards, Bureau of Mines regulations, and the mechanization at today's mines. Coal is either conveyed directly from the mine to the user, i.e., coke plant, or to the cleaning plant for transport to the user. Cleaning plants store coal in bins to facilitate transport and handling; little if any storage occurs in the open (personal communication with Mr. O'Brien, American Mining Congress, Environmental Matters Dept., July 30, 1974). The amount of coal stored is a function of the type of facility operated. Average coal storage supplies are as follows:

User	Average days of supply (D_S)	Effective	Annual days of operation (D_O)
Coke plants	23 (5)	August 1974	365 (6)
Electric utility stations	92 (7)	May 1974	365 (7)
Industrial	37 (5)	August 1974	205[a]

[a]Estimated value based on authors' industrial experience.

(1) Keystone Coal Manual, 1973. McGraw-Hill, Inc., New York, New York, 1973. pp. 304-410.

(2) Electric Utility Statistics. Public Power, 32:28-74, January-February 1974.

(3) Steam-Electric Plant Factors/1973 Edition. National Coal Association, Economics and Statistics Division, Washington, D.C., December 1973. 110 pp.

(4) Coke Producers in the United States in 1972. Mineral Industry Surveys. U.S. Department of the Interior,

The weight of coal stored is calculated from the product of the annual consumption of coal per user (1-4) and the ratio of average days of supply to annual days of operation (D_s/D_o).

Fugitive dust is emitted from an open coal storage pile via wind and other weathering forces acting on the surface. This process is similar to wind erosion of soil and this document uses many of the concepts already developed by other investigators of such phenomena to determine emissions from coal piles. Particulates are the most generally recognized of the emissions, but gaseous materials also emanate from coal storage piles by oxidation of the exposed coal and the release of pressure on the solid due to mining and comminution. Some volatile emissions are also generated during the weathering process. These gases may cause some odor at the pile; however, the chemical species which may contribute to this odor are not detectable at hazardous concentrations. Thus odor is not considered in this study.

2. Source Composition

There are four major classes of coal: 1) lignite, 2) bituminous, 3) subbituminous, and 4) anthracite (8). Coal usage breaks down as follows (9):

Class	Usage, 10^3 metric tons
Bituminous	330
Subbituminous	200
Lignite	10
Anthracite	6.4

Since anthracite and lignite account for less than 1.2% and 1.8%, respectively of the coal used in the United States (9), only the bituminous and subbituminous classes will be considered in this report.

Washington, D.C., November 27, 1973. pp. 2-5.

(5) Rumblings from the Mines. Time Magazine, 104(9):35,1974.

(6) Sheridan, E. T. Coke and Coal Chemicals. In: 1972 Minerals Yearbook, A. E. Schreck, ed. U.S. Department of the Interior, Washington, D.C., 1972. pp. 427-460.

(7) FPC Issues Electric Fuel Consumption Stocks. News Release No. 20499, Federal Power Commission, Washington, D.C., July 22, 1974. 3 pp.

(8) A.S.T.M. Standards on Coal and Coke. American Society for Testing and Materials, Philadelphia, Pennsylvania, September 1948. p. 80.

(9) Minerals Yearbook, 1973, Volume I. U.S. Department of the Interior, Washington, D.C., 1973. pp. 8-36.

Coal seams vary in physical and chemical properties across the U.S. However, coal dust is considered hazardous only on a mass basis and not by virtue of its composition. A TLV of 2 mg/m^3 applies to all classes of coal (10). Brown, Jacobs and Taylor (11) have studied trace elements in coal and coal dust. Table 1 has been developed from their data (10, 11). These results indicate that the heavier elements tend to concentrate in this dust. To determine the possible effect of these findings on the hazardous nature of the emissions from coal piles, a composite TLV (10) was calculated, using Equation 1 below, and compared to that of coal dust. The composite TLV of the mixture (T_M) was determined in order to take into account the effects of trace elements and other chemical compounds present in the coal dust. The TLV's of the metals and chemical forms that occur most frequently in coal dust (Table 2) were used for this analysis.

$$T_M = \frac{F_C}{\sum_{i=1}^{N} \frac{C_i}{T_i}} \qquad (1)$$

where $F_C = \sum_{i=1}^{N} C_i$ = total concentration of all elements in the dust

T_i = TLV of the ith element

C_i = concentration of the ith element (shown in Table 1)

N = number of elements, as given in Table 2

The composite TLV is thus 6 mg/m^3, as shown in Table 2, or three times that of coal dust. The largest contributor is the quartz component (1%). Analysis of dust samples from coal piles (Appendix A) shows that quartz is less than 1% and the composite TLV could be expected to be higher. Thus, analysis shows that coal dust can validly be considered the only hazardous pollutant emitted since the composite TLV is higher than the accepted TLV for mass coal dust.

---

(10) TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment and Intended Changes for 1973. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1973. p. 10.

(11) Brown, R., M. Y. Jacobs, and H. E. Taylor. A Survey of the Most Recent Applications of Spark Source Mass Spectrometry. American Laboratory, 4:34-37, November 1972.

TABLE 1. CONCENTRATIONS OF TRACE METALS IN COAL AND COAL DUST (11)

Element	Weight ppm in coal	Weight ppm in coal dust (C_i)
Aluminum	Major	283,000
Arsenic	0.30	26.4
Barium	69	453
Bismuth	0.20	7.50
Bromine	0.30	11.3
Boron	42	3.80
Cadmium	0.19	3.80
Calcium	4,000	13,200
Cerium	13	45.3
Chlorine	130	230
Chromium	4.5	170
Cobalt	2.3	11.3
Copper	25	868
Fluorine	5.7	1.90
Gallium	8.7	68.0
Germanium	0.33	18.9
Iodine	0.20	3.80
Iron	1,600	79,200
Lanthanum	5.8	22.6
Lead	3.9	26.4
Magnesium	4,500	792
Manganese	30	45.3
Molybdenum	3.0	15.1
Neodymium	8.3	45.3
Nickel	2.7	755
Niobium	20	7.60
Phosphorus	380	306
Potassium	410	16,600
Praseodymium	4.7	11.1
Rubidium	3.0	7.60
Samarium	1.7	3.80
Scandium	1.3	30.2
Selenium	0.32	7.60
Silicon	Major	294,000
Silver	0.22	7.60
Sodium	5,000	755
Strontium	100	291
Sulfur	6,100	3,130
Tellurium	0.25	3.80
Titanium	620	15,800
Uranium	1.9	2.26
Vanadium	12	166
Yttrium	7.7	7.60
Zinc	10	415
Zirconium	76	60.4

TABLE 2. COMPOSITE TLV OF ALL THE ELEMENTS IN COAL DUST

Element	C_i,[a] ppm	T_i(11), mg/m^3	C_i/T_i,[b] $\frac{(ppm)(m^3)}{mg}$
Aluminum	283,000	10	28,301.9
Arsenic	26.4	0.5	52.8
Barium	453	0.5	906.0
Bromine	11.3	0.7	16.1
Cadmium	3.80	0.2	19.0
Calcium	13,200	10	1,320.8
Chlorine	230	3	76.7
Chromium	170	1.0	170.0
Cobalt	11.3	0.1	113.0
Copper	868	1	868.0
Fluorine	1.90	2	1.0
Iodine	3.80	1	3.8
Iron	79,200	10	7,924.5
Lead	26.4	0.15	176.0
Magnesium	792	10	79.2
Manganese	45.3	5	9.1
Molybdenum	15.1	10	1.5
Nickel	775	1	775.0
Phosphorus	306	0.1	3,060.0
Potassium	16,600	10	1,660.4
Selenium	7.60	0.2	38.0
Silicon	284,000	10	28,434.0
Quartz	10,000	0.2	50,000.0
Silver	7.60	0.01	760.0
Sodium	775	10	77.5
Sulfur	3,130	2	1,566.0
Tellurium	3.80	0.1	38.0
Titanium	15,800	10	1,585.0
Uranium	2.26	0.2	11.3
Vanadium	166	0.5	332.0
Yttrium	7.60	1	7.6
Zinc	415	5	83.0
Zirconium	60.4	5	12.1
Other elements	289,000	10	28,941.7
Total	1,000,000		157,421.0

$$T_M = \frac{1,000,000^{b}}{157,421} = 6 \text{ mg/m}^3$$

[a] From Table 1.

[b] Intermediate calculated values are not rounded; rounding is performed on final answer.

B. FACTORS AFFECTING EMISSIONS

The major parameters that are known to contribute to the emissions from coal storage piles are pile geometry, coal erodibility (dustiness), wind, humidity, precipitation and temperature. Coal erosion has been studied in a wind tunnel and the effects of most of these parameters, or their equivalents, evaluated. Soil erosion equations have also been used to predict parameter influence on coal storage emissions. A complete discussion of these studies is provided in Appendix B. The following paragraphs summarize the findings.

The effects of humidity, precipitation and temperature can be combined into one parameter, the Thornthwaite precipitation-evaporation (P-E) index. P-E index values are available for all parts of the U.S. (12) and are shown in Figure 1. The lower the P-E index, the higher the emissions from coal piles. This parameter has the greatest effect on emission rate. The P-E ratio is calculated as follows:

$$\text{Monthly P-E ratio} = 11.5 \left(\frac{P_M}{T_M - 10} \right)^{10/9} \qquad (2)$$

$$\text{P-E index} = \sum_{i=1}^{12} \text{(monthly P-E ratios)}$$

where[a] P_M = monthly precipitation, in.
T_M = monthly mean temperature, °F, adjusted to a constant of 30°F for all values below 30°F

Coal erodibility is a measure of the dustiness of the coal. It has been shown that the bulk density of coal (ρ_b) is an indicator of coal dustiness. Thus, the erosion rate is a function of bulk density which has been used as the indicator of windblown emissions. The emission rate is influenced the least by this parameter.

Two remaining parameters that can contribute to emissions from coal storage piles are wind speed and pile geometry. A coal pile's

---

[a] Nonmetric units are designated for Equation 2 to conform to the system of units reported by the author (12) and commonly used.

(12) Thornthwaite, C. W. The Climates of North America According to a New Classification. The Geographical Review, 21:633-655, 1931.

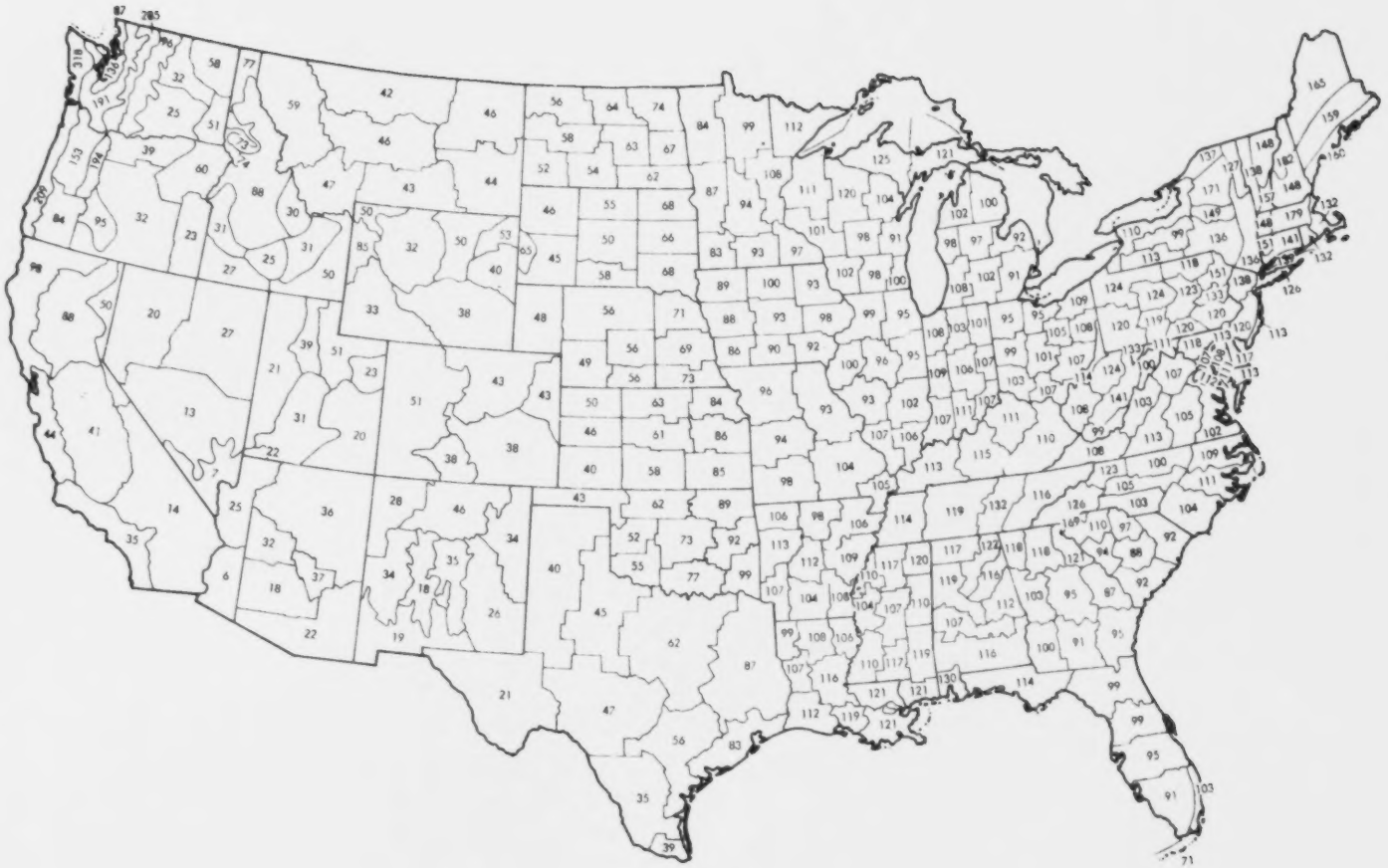


Figure 1. Map of P-E values for state climatic divisions (12).

geometry can be related through its surface area. Appendix C describes how this surface area can be calculated from the total weight stored.

A functional relationship could be derived relating all of these parameters to emission rate. This derivation is given in Appendix B, but it is not rigorously applied in this document. The rationale for this decision is given in Appendix B, which shows that the level of emissions from storage piles is adequately described through the use of an average emission factor which is given in Appendix A. The functional relationship of the emission parameters to emission rate is used to show the validity of using an emission factor.

C. GEOGRAPHICAL DISTRIBUTION OF COAL STORAGE PILES

Figure 2 shows the distribution of coal storage piles in the U.S. calculated as described in Section III.A.1. P-E index has the largest effect on emission rate. A comparison between the total weight stored per P-E region and the P-E index shows that 90% of the coal stored is located in P-E regions with indices between 90 and 130 (see Figure 3). This facilitates the use of an average emission factor for use in predicting the emission rates from the amount stored.

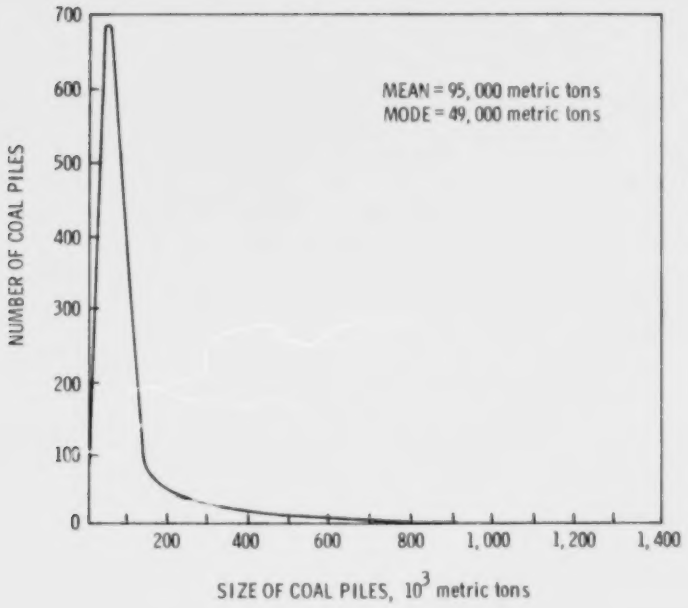


Figure 2. Distribution of coal piles.

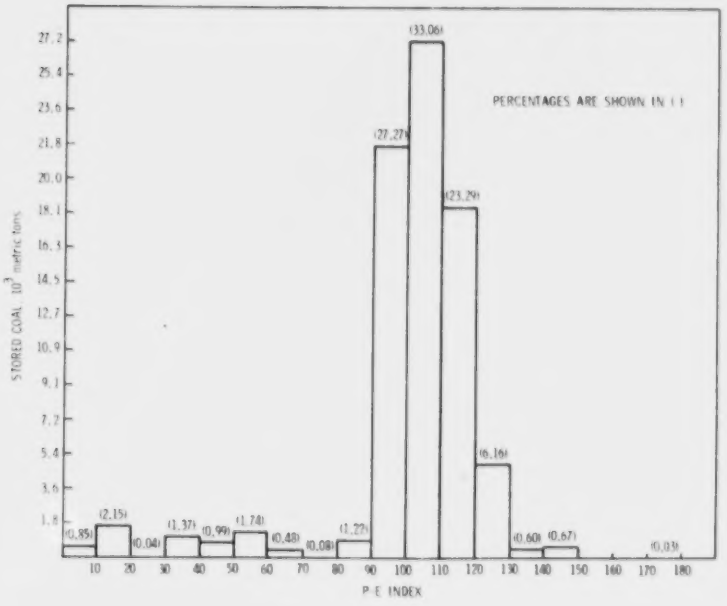


Figure 3. Distribution of quantity of coal stored versus P-E region.

SECTION IV

EMISSIONS

A. SELECTED POLLUTANTS

Wind erosion of coal storage piles results in the emission of coal dust. Long-term exposure to coal dust is the principal cause of coal mine workers' pneumoconiosis (13). The complicated stage of this disease is called progressive massive fibrosis and is characterized by massive destruction of lung tissue resulting in death from heart failure, asphyxia, or pneumonia (13). A TLV of 2 mg/m^3 is assigned to coal dust which is also a form of particulate matter and one of the five criteria pollutants. Since coal dust is a composite of various materials, the hazard potential of the composite can be calculated as the total of all ratios of trace element concentrations to the concentration required for a hazard potential equivalent to that of mass coal dust. This was calculated to be 6 mg/m^3 as shown in Table 2. Since the hazard potential of all trace elements is one-third the potential of mass coal dust (2 mg/m^3), further consideration of hazardous particulate emissions beyond coal dust is not necessary.

Oxidation of coal storage piles results in gaseous emissions such as hydrocarbons, ethane, carbon monoxide, and sulfur compounds. However, based on the results of sampling emissions at the surface and upwind of the pile (see Table 3), it can be seen that in all but four cases the upwind concentration of a gas was either nondetectable, or nearly equivalent to the concentration at the surface of the pile. This indicates that emissions from the pile were quantitatively nonexistent. The maximum concentrations reported between upwind and pile samples are not of significance either. This can be shown by comparing samples G_3 and G_4 for methane and total hydrocarbons, and by comparing samples G_5 and G_6 for carbon monoxide. These pile concentrations are reduced

---

(13) Brown, M. C. Pneumoconiosis in Bituminous Coal Miners. Mining Congress Journal, 51:44-48, August 1965.

(14) Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education, and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

TABLE 3. ANALYSIS OF GRAB SAMPLES FOR TOTAL HYDROCARBONS, METHANE, CARBON MONOXIDE AND SULFUR (AS H_2S, SO_2 AND RS)

Sample description	Concentration, ppm by volume[a,b]			
	Total[c] hydrocarbons	Methane	Carbon monoxide	Sulfur
G_1 - Coal pile #1	3.5	1.5	N.D.[d]	N.D.
G_2 - Upwind of pile #1	3.2	1.4	N.D.	N.D.
G_3 - Coal pile #2	60	60	9.0	N.D.
G_4 - Upwind of pile #2	3.9	1.6	N.D.	N.D.
G_5 - Coal pile #3	5.0	1.5	19.0	N.D.
G_6 - Upwind of pile #3	3.0	1.6	1.0	N.D.
G_7 - Coal pile #4 (No background near power plant)	8.0	3.0	12.0	5.0
G_8 - Coal pile #5 (active)[e]	4.0	3.0	5.0	N.D.
G_9 - Coal pile #5 (inactive)[e]	3.0	2.0	1.0	N.D.
G_{10} - Upwind of pile #5	5.0	2.0	1.0	N.D.
G_{11} - Coal pile #6	4.5	3.0	1.0	N.D.
G_{12} - Upwind of pile #6	3.0	4.0	1.0	N.D.

[a] Sensitivity for total hydrocarbons and methane is ±1 ppm and <1 ppm for CO and sulfur compounds.

[b] Samples of trapped gases, collected in glass flasks through a probe inserted in the coal piles. This method is described in Appendix D.

[c] Expressed as methane equivalent.

[d] None detected (<1 ppm).

[e] Active and inactive refer to the use of the pile. Inactive piles are coated with a tar or oil to prevent oxidation.

by at least three orders of magnitude at a position 50 m from the pile (14) (with assumed stability class, C, and mean speed of 4.5 m/s). This puts them well below ambient air quality standards and these gases do not merit further consideration.

B. MASS EMISSIONS

The particulate emission factor for a coal storage pile has been shown to be 6.4 mg/kg-yr (Appendix A). The use of this average emission factor describes the emissions within 108% at the 95% confidence level. The major influencing factor is the P-E index; however, 90% of the coal stored is located in P-E regions of 90 to 130 (see Figure 3) which reduces the effect on emissions to ±40% from the possible ±8,500% described in Appendix B. This emission factor is used in conjunction with the distribution of coal storage piles (Figure 2) to give the distribution of emissions. The mean emission rate will thus be 606 kg/yr. State and national emissions burdens are given in Table 4.

For a comparison to other data in the literature, the Woodruff and Siddoway equation referenced in Appendix B was used to calculate an emission factor for bare, noncrusted, unsheltered and isolated fields. This factor is 445 mg/kg-yr in comparison to the 6.4 mg/kg-yr of coal storage piles. This is reasonable since visual dust clouds from coal piles are rarely observed in comparison to barren fields. Only two complaints concerning dust due to coal storage have been recorded, one in Illinois and another in Minnesota[a]. In addition, the emissions from barren fields contain only about 1% to 2% respirable particles (<7 μm). Thus, the respirable emission factor for fields is 6.7 mg/kg-yr. This is within 3% of the mass emission factor for coal piles which is for respirable particulate.

C. REPRESENTATIVE SOURCE

The representative coal pile is defined as containing 95,000 metric tons of bituminous coal piled to an average height of 5.8 m. It is located in a P-E region of 91 index with an average annual wind speed of 4.5 m/s and is 86 m from the nearest plant boundary. These are the mean characteristics of all known coal piles. The emissions from the representative pile average 606 kg/yr of coal dust.

Sampling was conducted at a coal pile containing an average of 112,000 metric tons of bituminous coal. It was located in a P-E region of 103 index with an average annual wind speed of 3.5 m/s. The emissions from the sampled coal pile averaged 715 kg/yr. During the sampling period, the wind speed averaged 1.9 m/s and

---

[a]These have never been substantiated or quantified as being from the coal storage piles.

TABLE 4. STATE AND NATIONAL EMISSIONS

State	State emissions, 10^6 metric tons	Coal stored, 10^6 metric tons	Coal emissions, metric tons	Percent of total emissions
West Virginia	1.3	5.0	32	0.0026
Ohio	3.0	10	66	0.0022
Pennsylvania	3.1	9.8	63	0.0020
Indiana	2.2	6.7	42	0.0019
Kentucky	1.8	5.2	33	0.0018
Alabama	2.0	4.5	29	0.0014
Tennessee	1.8	3.8	24	0.0014
Illinois	3.6	7.2	46	0.0013
Michigan	2.8	5.6	36	0.0013
North Carolina	2.2	4.5	29	0.0013
Delaware	0.13	0.27	1.7	0.0013
Maryland	0.66	1.3	8.1	0.0012
Wisconsin	2.2	2.8	18	0.00082
Missouri	2.8	3.1	20	0.00070
U.S. Total	135	98.6	629	0.00047

the P-E index was estimated to average 48. It has been shown that the factor affecting emissions is the ratio of the cube of the wind speed to the square of the P-E index. The sampling conducted is close to representative even though the wind speed and P-E index were lower than the average conditions. Table 5 compares the values of the factors affecting the emissions for the representative coal storage piles, and the selected pile. There is agreement within a factor of two during average conditions and sampling conditions between the representative coal pile and the pile selected for sampling. In addition, there is statistical agreement between the average and sampling conditions for the selected pile.

TABLE 5. COMPARISON OF THE REPRESENTATIVE COAL STORAGE PILE TO THE PILE SELECTED FOR SAMPLING

Parameter	Representative pile at U.S. average conditions	Sample pile	
		Average conditions	Conditions at the time of sampling
u, m/s	4.5	3.6	1.9
P-E index	91	103	48
Size, 10^3 metric tons	95	112	112
s, m^2	20,500[a]	41,400[b]	41,400[c]
$\frac{u^3 s^{0.35}}{(\text{P-E index})^2}$	0.35	0.18	0.12 ± 0.15[c]
Emission rate, kg/yr	606 ± 648[c]	715	716 ± 657[c]

[a]Area from derivation described in Appendix C.

[b]Area of coal storage pile from Table A-2 of Appendix A.

[c]At 95% confidence level.

D. ENVIRONMENTAL EFFECTS

Two types of severity[a] are addressed for coal storage piles: gross particulate and mass coal dust. All other emissions have been shown to be negligible or were not detected in measurable quantities. Since the gross particulate emission is 100% coal dust, the concentrations downwind are the same and the only difference will be the hazard factor.

1. Ground Level Concentration

The minimum distance from the representative coal pile to the nearest plant boundary has been determined, as described in Appendix F, to be 86 m. This is the distance to the point at

[a]A complete derivation and definition of severity are provided in Appendix H.

which the highest concentration would be observed under class C meteorological conditions (approximate U.S. average). The following formula was used to calculate this concentration which shall be defined as χ_{max} (14).

$$\chi_{max} = \frac{Q}{\pi \sigma_y \sigma_z} \qquad (3)$$

where Q = mass emission rate, g/s
$\sigma_y = 0.209\ x^{0.903}$
$\sigma_z = 0.113\ x^{0.911}$
$u = 4.5$ m/s

This instantaneous ground level concentration at 86 m is 18 $\mu g/m^3$. This must be corrected to the time-averaged maximum, χ_{max}, for 24 hours as described by Nonhebel (15) so that the mean concentration becomes 6.4 $\mu g/m^3$.

2. Hazard Factor

The hazard factor, F, is defined as follows for coal dust and is used to determine source severity:

$$F = \frac{8}{24} \cdot \frac{1}{100} \cdot TLV \qquad (4)$$

The derivation of F utilizes the TLV corrected from 8-hour to 24-hour exposure with a safety factor of 100 applied to this calculation. The hazard factor for most coal dust is calculated as 6.7 $\mu g/m^3$. For gross particulates, F shall be defined as the 24-hour ambient air quality standard of 260 $\mu g/m^3$.

3. Source Severity

For the representative coal pile, the maximum severity is determined from the ratio, χ_{max}/F. The various applicable severities are given in Table 6. The area affected down to a severity of 0.1 is determined using Figure 4 and Table 6 as described below.

The distance from the coal pile to a coal dust severity of 0.1 is determined to be 528 m. To this is added the radius of the pile, 80 m, since the expression for Q was derived using the edge of the pile as a reference. The resulting area of severity involved is thus 1.2×10^6 m^2. From this is subtracted the area of the plant to represent nonpublic exposure to a severity greater than 0.1. The representative population density is then multiplied

---

(15) Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

TABLE 6. SOURCE SEVERITY

Distance, m	Coal dust severity	Particulate severity
86	1.0	0.025
528	0.1	-

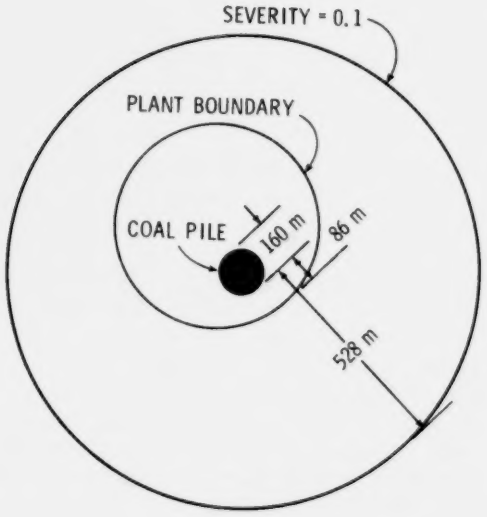


Figure 4. Area affected down to a severity of 0.1.

by the resulting area to give population exposed. The population affected to a severity of 0.1 is 58 persons. The calculation of the area affected to a severity of 0.1 is shown below.

Area of severity involvement = $\pi(528\ m + 80\ m)^2 = 1.2 \times 10^6\ m^2$

Area of plant = 10 (area of pile) = 200,000 m^2

Area of affected population = 960,000 m^2

Population affected (from Appendix F) = (61 persons/km^2) x $(0.96\ km)^2$ = 58 persons.

SECTION V

CONTROL TECHNOLOGY

A. STATE OF THE ART

There is no established air pollution control technology for coal storage piles. Emissions from coal piles are not commonly recognized as a pollution problem. However, the practices of coating some coal piles with tar derivatives, receiving some coal in a moist state from cleaning plants, and storing coal outside where it is subjected to precipitation, all unintentionally control the entrainment of coal dust.

Coal is coated with tar derivatives to prevent spontaneous combustion of the pile. Oxidation of volatile components of the coal releases heat which, when concentrated, can cause the coal pile to spontaneously ignite. Coating of the coal shields it from atmospheric oxidation. In additon, the tar also causes the coal dust to adhere to the pile. This increases the resistance of coal dust to wind entrainment. Conventional spray (60 parts coal tar:40 parts water) is generally effective for 15 days. However, other emulsions have been effective for 25 days to 35 days (16). When coal is received at the user site from the cleaning plant, it may still contain excess moisture. Moisture retained within the coal functions in a manner similar to the tar coatings described by causing the coal dust to adhere to the pile and increase the resistance to wind entrainment. Storage of coal outdoors exposes it to rain and snow which also creates this condition.

B. FUTURE CONSIDERATIONS

There is no control technology under consideration for coal storage piles. If a need for control were established through an assessment of the source, initial emphasis would be placed on reduction of the primary vehicle of dust entrainment, the wind speed. Wind speed has an effect of ±160% on emission rate of dust particles with P-E index, bulk density, and surface area values kept constant.

---

(16) Fuju, K., T. Adachi, Y. Tsukaoa, K. Okuda, and H. Suzuki. Coal Dust Scattering Preventative. Japanese Patent 73 24,983 (to Nihon Koken Kogyo Co., Ltd.), March 31, 1973. 5 pp.

Reduction of wind speed is possible by construction of barriers around a coal pile and storage of coal in a pit or silo. The height of such barriers must be greater than the height of the pile since the wind will tend to project over the barriers onto the pile. Design criteria for barrier construction must also enable easy removal and addition of coal to allow this control method to be economically feasible.

Storage of coal in a pit or silo, where possible, appears to be the more economical and effective means of wind speed reduction. Coal stored within a pit or silo is shielded from wind forces, and is less susceptible to spillage in the area around storage during loading and unloading. Coal pile spillage is particularly prone to emission because the greater surface area exposed to the wind permits faster drying of the coal. The spilled coal may thus create greater amounts of coal dust than does the coal pile.

The present practices of coating coal with tar derivatives or increasing the water content of coal both suppress dust entrainment. However, continued employment of this practice may generate additional pollutants. When tar is sprayed onto a coal pile, particulates are emitted from the overspray. The solvent content of the tar applied is also released upon combustion of the tar coating on the coal.

Addition of water to the coal also suppresses dust entrainment, but requires that the coal be dried prior to combustion. Thermal drying of coal entails a combustion process which may generate additional pollutants. It is also an expensive process and may not be economically feasible.

SECTION VI

GROWTH AND NATURE OF THE INDUSTRY

A. PRESENT AND EMERGING TECHNOLOGY

Coal storage piles are located outdoors to facilitate the loading and/or unloading of coal. Outdoor storage also inhibits spontaneous combustion caused by atmospheric oxidation. Wind passing over the coal reduces the concentration of heat within the pile. However, coatings are necessary to prevent ignition of the coal in areas with high temperatures and low wind speeds.

It is anticipated that coal will continue to be stored outdoors in the future. Coal users are expected to locate new plants near mines to reduce transport costs, assure supplies, and avoid the stricter environmental standards of more densely populated areas.

The number of coal piles is increasing as the United States uses more and more coal as an energy source. Coal consumption is anticipated to increase by 7% per year over the next 10 years (17). Coal inventories (days of supply) are expected to increase by 3.8% per year, which will cause an increase in emission rate of 25% by 1978 compared to 1972.

B. COAL STORAGE TRENDS

Usage of coal in the U.S. has followed a curious pattern. Consumption in 1912 was equivalent to consumption in 1970 (18), when coal accounted for 20% of the total energy input of the United States.

---

(17) Rieber, M., and R. Halcrow. U.S. Energy and Fuel Demand to 1985. CAC No. 108R (PB 239 343), National Science Foundation, Washington, D.C., May 1974. 44 pp.

(18) Hottel, H. C., and J. B. Howard. New Energy Technology - Some Facts and Assessments. MIT Press, Cambridge, Massachusetts, 1971. pp. 3-4.

Coal is projected to constitute 30% of energy input, with electric utilities predicting an increase of 100% to 275% in the use of coal by 1985 (19).

Utilities will tend to build new facilities near mines, water supplies, and on large plots of land. Coal storage piles will thus be located in areas of lower population density and will be farther from local communities. With more land available, future coal piles can be expected to be larger to meet the growing energy needs of the country. Coke plants and industrial boiler facilities are expected to follow the general trends of the utilities because they face similar energy situations and propose similar solutions.

---

(19) Roach, J. W. U.S. Energy Outlook - Fuels for Electricity. U.S. Department of the Interior, Washington, D.C., 1973. p. 4.

REFERENCES

1. Keystone Coal Manual, 1973. McGraw-Hill, Inc., New York, New York, 1973. pp. 304-410.

2. Electric Utility Statistics. Public Power, 32:28-74, January-February 1974.

3. Steam-Electric Plant Factors/1973 Edition. National Coal Association, Economics and Statistics Division, Washington, D.C., December 1973. 110 pp.

4. Coke Producers in the United States in 1972. Mineral Industry Surveys. U.S. Department of the Interior, Washington, D.C., November 27, 1973. pp. 2-5.

5. Rumblings from the Mines. Time Magazine, 104(9):35, 1974.

6. Sheridan, E. T. Coke and Coal Chemicals. In: 1972 Minerals Yearbook, Schreck, A. E. ed. U.S. Department of the Interior, Washington, D.C., 1972. pp. 427-460.

7. FPC Issues Electric Fuel Consumption Stocks. News Release No. 20499, Federal Power Commission, Washington, D.C., July 22, 1974. 3 pp.

8. A.S.T.M. Standards on Coal and Coke. American Society for Testing and Materials, Philadelphia, Pennsylvania, September 1948. p. 80.

9. Minerals Yearbook, 1973, Volume I. U.S. Department of the Interior, Washington, D.C., 1973. pp. 8-36.

10. TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment and Intended Changes for 1973. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1973. p. 10.

11. Brown, R., M. Y. Jacobs and H. E. Taylor. A Survey of the Most Recent Applications of Spark Source Mass Spectrometry. American Laboratory, 4:34-37, November 1972.

12. Thornthwaite, C. W. The Climates of North America According to a New Classification. The Geographical Review, 21:633-655, 1931.

13. Brown, M. C. Pneumoconiosis in Bituminous Coal Miners. Mining Congress Journal, 51:44-48, August 1965.

14. Turner, D. B. Workbook of Atmospheric Dispersion Estimates. Public Health Service Publication No. 999-AP-26, U.S. Department of Health, Education and Welfare, Cincinnati, Ohio, May 1970. 84 pp.

15. Nonhebel, G. Recommendations on Heights for New Industrial Chimneys. Journal of the Institute of Fuel, 33:479, 1960.

16. Fuju, K., T. Adachi, Y. Tsukaoa, K. Okuda, and H. Suzuki. Coal Dust Scattering Preventive. Japan Patent No. 73 24,983 (to Nihon Koken Kogyo Co., Ltd.), March 31, 1973. 5 pp.

17. Rieber, M., and R. Halcrow. U.S. Energy and Fuel Demand to 1985. CAC No. 108R (PB 239 343), National Science Foundation, Washington, D.C., May 1974. 44 pp.

18. Hottel, H. C., and J. B. Howard. New Energy Technology - Some Facts and Assessments. MIT Press, Cambridge, Massachusetts, 1971. pp. 3-4.

19. Roach, J. W. U.S. Energy Outlook - Fuels for Electricity. U.S. Department of the Interior, Washington, D.C., 1973. p. 4.

20. Singer, J. M., F. B. Cook, and J. Gurmer. Dispersal of Coke and Rock Dust Deposits. Bureau of Mines RI-7642, U.S. Department of the Interior, Pittsburgh, Pennsylvania, 1972. 32 pp.

21. Dawes, J. G. Dispersion of Dust Deposits by Blasts of Air - Part 1. Research Report No. 36, Ministry of Fuel and Power, Safety in Mines Research Establishment, Sheffield, England, May 1952. 69 pp.

22. Woodruff, N. P., and F. H. Siddoway. A Wind Erosion Equation. Soil Science Proceedings, 29:602-608, May 1952.

23. Bagnold, R. A. The Physics of Blown Sand and Desert Dunes. Metheun and Co., London, England, 1954. 265 pp.

24. Shafer, H. J. A model Study of the Reduction of Wind Transport of Fine Particles by Aerodynamic Barriers. Presented at the Fifth Annual Conference on Aviation and Astronautics, Tel Aviv and Haifa, Israel, 1963. pp. 57-63.

25. Woodruff, N. P., and W. S. Chepil. Sedimentary Characteristics of Dust Storms II - Visibility and Dust Concentration. American Journal of Science, 2:104-114, February 1957.

26. Cowherd, C., K. Axetell, Jr., and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

27. Jutze, G. A., K. Axetell, and W. Parker. Investigation of Fugitive Dust - Sources, Emissions, and Controls. EPA Contract 68-02-0044, Task Order 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 61 pp.

28. Annual Report of Research and Technologic Work on Coal. Bureau of Mines IC-7518, U.S. Department of the Interior, Washington, D.C., 1949. p. 39.

29. Federal Register, 36(228), November 25, 1971.

30. Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

31. Tadmor, J., and Y. Gur. Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion. Atmospheric Environment, 3(6):688-689, 1969.

32. Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 113.

33. Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 pp.

APPENDIX A

ANALYSIS OF SAMPLING RESULTS

1. MASS EMISSIONS RATES

Four sampling runs were performed during two different periods, March and August 1974, at a coal pile site. Sampling equipment and procedures are described in Appendix D. Since the variability of emissions from a single coal pile is greater than the variations between coal piles (see Appendix B.3.c. for basis) the results were considered as four separate samples at one coal pile. The positions of the samplers during March and August are shown respectively in Figures A-1 and A-2. Except for one day, coal was not being transferred or moved at the pile by bulldozers during the sampling. This activity would be expected to generate additional dust that was not due to the storage of coal. In fact, there was no statistical difference noted. In addition, the pile selected for sampling was located in a rural, non-industrialized area in order to avoid any possible interference from particulates generated at other sources.

The sampler labeled S_o was positioned upwind of the pile for use as a reference to the particulate concentration in the atmosphere, prior to the addition of particulates from the coal pile. Subtraction of the concentration level at S_o from the concentrations obtained at downwind samples S_1 through S_4 yielded the concentration levels due to the emissions from the coal pile. Turner's atmospheric dispersion equation (14) was then used to calculate the mass emission rate, Q, from the coal pile:

$$Q = \chi_y \sigma_z \pi u \qquad \text{(A-1)}$$

where χ = concentration with no effective plume rise
π = 3.14
$\sigma_y \sigma_z$ = horizontal and vertical dispersion as a function of downwind distance and atmospheric stability
u = mean wind speed

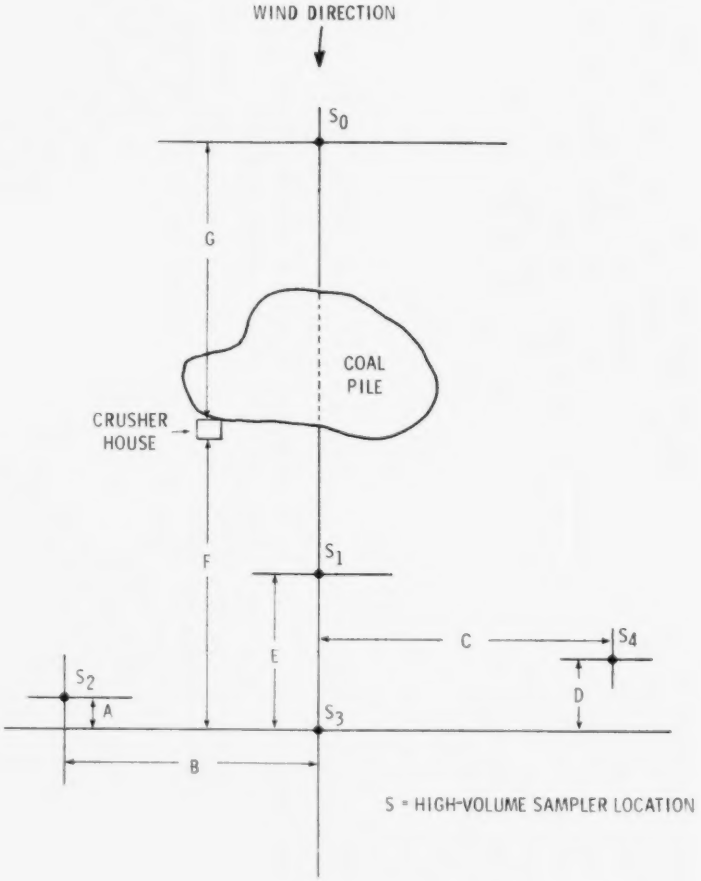


Figure A-1. March sampling arrangement, runs C1 and C2.

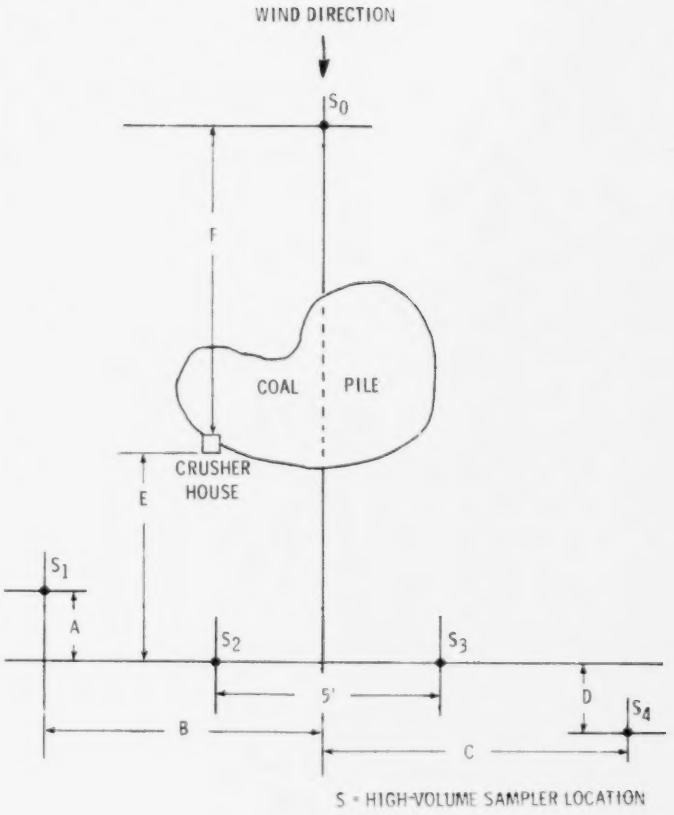


Figure A-2. August sampling arrangement, runs CS-3 and CS-5.

a. Mean Emission Factors

The mean emission factor for all the emission rates calculated at each of the sampler positions is 6.4 mg/kg-yr with a sample standard deviation of 2.54 (Table A-1). However, the errors associated with sampling and the use of Equation A-1 are combined as shown in Appendix E to yield an overall standard deviation of 4.3. Since confidence limits are calculated as follows,

$$\text{C.L. (@ 95\% level)} = \frac{t \cdot \sigma}{\sqrt{n}} \qquad \text{(A-2)}$$

where σ = estimated population deviation
t = "Student t" value for n-1 degrees of freedom @ 95% level
n = number of samples

and $\sigma = 4.3$
$n = 4$
$t = 3.182$

the 95% confidence limits are 6.9 using the emission factor of 6.4 mg/kg-yr.

b. Correlation With Factors Affecting Emissions

Emission rate is calculated from Equation B-18, Appendix B (shown here for reader convenience):

$$Q = \frac{k u^a \rho_b{}^b s^c}{(P-E)^d} \qquad \text{(A-3)}$$

where Q = emission rate, mg/s
k = constant
u = wind speed, m/s
ρ_b = bulk density, g/cm^3
s = surface area
$P-E$ = Thornthwaite's precipitation-evaporation index (or P-E index)

In order to apply this equation in determining the extent of emissions from all 950 coal piles, the most probable exponents were chosen from similar wind erosion studies performed on coal piles. In Appendix B, the following exponents for the parameters of Equation A-3 were presented:

$2.7 \leq a \leq 3.0$ (wind speed)
$2.0 \leq b \leq 5.9$ (bulk density)
$c = 0.345$ (surface area)
$d = 2.0$ (P-E index)

TABLE A-1. SAMPLING RESULTS - MARCH AND AUGUST 1974

Run number Date	C1 3/28/74	C2 3/27/74	CS-3 8/20/74	CS-5 8/22/74
Parameter	**Value**			
Wind speed, m/s	2.7	1.7	1.5	1.5
Wind direction, radians	+1.08	+0.633	-0.680	+0.140
(°)	(+61.6)	(+36.3)	(-39)	(+8)
Wind direction range, radians	0.701	0.914	0.489	1.03
(°)	(40.2)	(52.4)	(28)	(58.9)
Atmospheric stability class	B	B	B	B
Distance, m A[a]	13.4	28.2	12.8	4.3
" " B	37.5	44.8	41.1	30.5
" " C	23.8	24.7	15.8	54.9
" " D	13.4	26.5	7.6	3.0
" " E	34.4	45.1	13.7	42.7
" " (estimated) F	73.2	91.4	122	152
" " (estimated) G	396	122	(none)[b]	(none)
Wet bulb temperature, °C	11.9	7.80	22.2	22.2
Dry bulb temperature °C	15.3	11.7	29.4	29.4
Barometric pressure, kPa	99.2	101	100	100
(mm Hg)	(744)	(754)	(752)	(751)
Concentration at S_0, ug/m^3	75	55	58	138
" S_1 "	107	60	63	341
" S_2 "	127	84	83	420
" S_3 "	112	71	140	391
" S_4 "	106	55	89	262
Dust <10 μm,[c] %	100	100	100	100
Moisture in source, %	10	11	2.3	2.2
Emission rate, mg/s	22.4	12.9	14.2	41.3
Sample standard deviation, mg/s	15.1	7.10	11.4	13.2
Coal stored, 10^3 metric tons	89.4	89.4	134	134
Emission factor, mg/kg-yr	7.91	4.55	3.34	9.72

[a] See Figures A-1 and A-2.

[b] Elevated 4.6 m.

[c] See Appendix A.3. on particle size distribution.

Average emission factor = 6.38 mg/kg-yr
Sample standard deviation = 2.54 mg/kg-yr
Estimated population standard deviation = 2.94 mg/kg-yr

For wind speed, seven different studies were cited (Appendix B) relating the effect of wind speed to emission rate. Each of these studies was conducted over specified ranges of wind speed. Coal storage piles are subjected to mean wind speeds in the range of 1.3 to 6.7 m/s. For this range the effect on emission rate can be closely approximated by $Q \alpha u^3$. Therefore, u^3 can be established as the relationship representing the effect of wind speed. Two studies were cited (Appendix B) that relate the effect of bulk density to emission rate. The first study, by Singer, Cook, and Grumer (20), determined the effect on bulk density to be represented by $Q \alpha \rho_b^{5.9}$. However, this study was performed on "free-flowing" deposits of coal particles. These deposits were composed of particles between 100 μm and 150 μm in size. In the assessment of coal storage, from a hazard potential standpoint, only those particles within the respirable range (less than 7 μm) are of interest. Therefore, the effect of bulk density represented by $\rho_b^{5.9}$ is discarded. The second study was performed by Dawes (21) who related bulk density to emission rate as $Q \alpha \rho_b^2$. In this study no specific mention of the particle size range under analysis was cited; however, particles were classified as fine coal dust, which is the class of particles expected from coal storage emissions. Therefore, the effect of bulk density on emission rate in this study is represented by ρ_b^2.

Only one relationship was established for surface area, and this was obtained via regression analysis of the Singer, Cook, and Grumer study. Surface area was found to be related to emission rate by $Q \alpha s^{0.345}$.

The remaining parameter, Thornthwaite's precipitation-evaporation index, has also been analyzed by various investigators. All studies indicated that surface moisture, as represented by the P-E index (which has values for each climatic region), was approximated by $Q \alpha (P-E)^{-2}$. Therefore, Equation A-3, through the use of these most probable exponents, becomes:

$$Q = \frac{k u^3 \rho_b^2 s^{0.345}}{(P-E)^2} \qquad \text{(A-4)}$$

where k is a constant.

---

(20) Singer, J. M., F. B. Cook, and J. Gurmer. Dispersal of Coke and Rock Dust Deposits. Bureau of Mines RI-7642, U.S. Department of the Interior, Pittsburgh, Pennsylvania, 1972. 32 pp.

(21) Dawes, J. G. Dispersion of Dust Deposits by Blasts of Air-Part 1. Research Report No. 36, Ministry of Fuel and Power, Safety in Mines Research Establishment, Sheffield, England, May 1952. 69 pp.

To obtain the value of the constant without further sampling, the sampling results in Table A-1 were fitted to Equation A-4. The data (from Table A-1) used in calculating k from Equation A-4 are listed in Table A-2. The resulting arithmetic mean value of the constant k from the four runs is 336 with an estimated standard deviation of 200. Equation A-4 then becomes:

$$Q = (336)\ \frac{u^3 \rho_b{}^2 s^{0.345}}{(P-E)^2} \qquad \text{(A-5)}$$

where Q is in mg/s.

The error associated with the use of Equation A-5 must be corrected for the error in determining Q as shown in Appendix E. Therefore, the estimated population standard deviation becomes 261 and the 95% confidence limits are ±416.[a]

2. COMPOSITION

Filters were analyzed for major elements by x-ray fluorescence as described in Appendix D. Results of this analysis are given in Table A-3. In addition, an infrared analysis was performed for free silica and it was concluded that less than 1% is present in the dust samples.

3. PARTICLE SIZE ANALYSIS

The filters were subjected to microscopic evaluation as described in Appendix D. The results, reported in Table A-4, indicated few particles greater than 10 μm in size. Because of the low emission rate only one Brink® sample was obtained. Eighty-eight percent of the particles from a composite sample taken over the 2 sample days in August were less than 5 μm in size. Based upon this evidence, it is concluded that essentially all of the emissions are in the respirable range.

[a] This assumes that there are four samples taken. In reality the number lies between two and four for each parameter evaluated. Four was chosen to represent the best case for this error.

TABLE A-2. DATA FOR CALCULATION OF THE CONSTANT (k)

Run number Date		C1 3/28/74	C2 3/27/74	CS3 8/20/74	CS5 8/22/74
Parameter		Value			
Wind speed (u), m/s		2.7	1.7	1.5	1.5
Bulk density (ρ_b), g/cm^3		0.8	0.8	0.8	0.8
Quantity stored (W_t), 10^3	metric ton	89.4	89.4	134	134
Avg. pile height (h), m		3.6	3.6	4.6	4.6
Surface area (s), m^2		46,500	46,500	36,400	36,400
Weeks precipitation, mm		17.5	17.5	14.5	14.5
Avg. temperature, °C		15.3	11.7	29.4	28.3
P-E index (estimate)		60.5	70.7	30.8	31.8
Emission rate (Q), mg/s		22.4	12.9	14.2	41.3
k		159.7	503.1	166.5	516.1

Arithmetic mean value of k: 336
Standard deviation (estimate): 200

TABLE A-3. X-RAY FLUORESCENCE ANALYSIS OF SAMPLES FROM FILTERS

Element	Filter #2 g/m^2	Filter #9 g/m^2	Filter #11 g/m^2
Sodium	0.01	0.05	0.01
Magnesium	<0.01	<0.01	<0.01
Aluminum	a	a	a
Silicon	b	b	b
Sulfur	0.04	0.05	0.13[c]
Chlorine	<0.01	<0.01	<0.01
Potassium	<0.01	<0.01	<0.01
Copper	<0.02	<0.02	<0.02
Titanium	a	N.D.[d]	a
Chromium	a	N.D.	a
Manganese	a	N.D.	a
Iron	0.03	<0.01	0.02

[a] Denotes presence possible, but just above background, probably less than 0.001 g/m^2.

[b] Denotes presence likely, but unable to provide an estimate due to interference of tungsten in line (from x-ray tube) as well as high counts in this region from the Nucleopore® filter blank.

[c] No other metal seems to be associated with the increase in sulfur content. This may suggest presence of organic sulfur, sulfuric acid, etc.

[d] <0.0006 g/m^2.

TABLE A-4. PARTICLE SIZE ANALYSES

Sample B1			Sample B2		
Size range, µm	Number of particles	Wt. %[a]	Size range, µm	Number of particles	Wt. %[a]
0 to 1.2	102	0.10	0 to 1.2	93	0.48
1.2 to 2.4	123	0.76	1.2 to 2.4	106	3.20
2.4 to 4.8	34	1.67	2.4 to 4.8	31	7.48
4.8 to 9.6	16	6.29	4.8 to 9.6	14	27.04
9.6 to 19.2	5	15.72	9.6 to 19.2	4	61.80
19.2 to 38.4	3	75.46	19.2 to 38.4	0	0
38.4 to 76.8	0	0			
Fibers:	0		Fibers:	0	

[a]These conversions of particle number to weight percent are estimates only and assume spherical particles of uniform density.

APPENDIX B

FACTORS AFFECTING COAL STORAGE EMISSIONS

1. INFORMATION

In this source assessment a study was made to determine the factors that affect emissions and/or entrainment rates for open coal storage piles. Unfortunately, no data directly applicable to this pollutant source were available. However, data from investigations of somewhat similar problems were readily available.

The bulk of the empirical relationships expressed in this study were derived from the results of wind tunnel experimentation conducted by the Pittsburgh Mining and Safety Research Center, Pittsburgh, Pennsylvania (20). This study was performed to determine minimum air velocities and entrainment rates for coal bed and rock dust dispersion under conditions that simulate dispersion from surfaces in coal mines where airflows are induced by weak explosions. The investigation analyzed the effect of a number of factors also believed to influence wind erosion of open coal storage piles. These variables are:

- Wind velocity at the midheight of the coal dust bed, u_L, m/s
- Bulk density of the coal dust bed, ρ_b, g/cm^3
- Surface area of the coal dust bed, s, cm^2
- Leading angle at the base of the coal dust bed, A_L, degree (free-flowing deposits only)
- Volume of the coal dust bed, V, cm^3
- Height of the coal dust bed, H, cm
- Width of the coal dust bed, W, cm (cohesive deposits only)

Data presented were of a rather limited nature, encompassing an extremely narrow range of values for each variable. Dust bed geometry data were particularly limited in all dimensional aspects. Dust bed composition was limited to two principal classifications:

- Free-flowing coal dust beds, limited to particles 100 μm to 150 μm in diameter
- Cohesive coal dust beds, containing particles 6 μm to 80 μm in diameter

The two types of dust beds differed not only in particle size distribution, but also in their respective modes of dispersion. At the high wind velocities (considered 10 to 60 mph), free-flowing deposits were entrained by single particle detachment while cohesive deposits dispersed by clump removal.

Since open coal storage piles are rarely subjected to wind speeds capable of initiating dispersion by clump removal, empirical relationships derived from experimentation on free-flowing deposits are considered more applicable to open coal storage.

2. DERIVATION OF PARAMETERS

a. Wind Velocity, u_L, u_{ave}, (m/s)

Relationships between entrainment and wind velocity have already been derived (21):

$$E_n \propto u_L^{2.1} \text{ or } E_n \propto u_{ave}^{2.7} \qquad \text{(B-1)}$$

where E_n = entrainment rate, g/s of free-flowing dust beds
u_L = air velocity in the wind tunnel at the midheight of the dust bed, m/s
u_{ave} = mean air velocity in the wind tunnel, m/s

Other investigators have derived similar relationships:

Entrainment rate	Wind speed range, m/s	Reference
$E_{SO} \propto v^3$	1.3 to 6.7	22
$E_{SA} \propto Fu^3$	>4.5	23
$E_{SA} \propto u_{ave}^{2.7}$	4.5 to 8.9	20
$E_n \propto u_{ave}^3$	>6.7	21
$E_p \propto v_F^9$	0 to 0.9	24
$E_S \propto v^9$	<1.3	25
$E_A \propto v^3$	1.3 to 8.9	26

where all E terms are symbols for entrainment rate and wind velocity is expressed as Fu, u, or v.

b. Bulk density, ρ_b, (g/cm^3)

Relationships between entrainment rate and bulk density have already been derived (20).

$$E_n \propto \rho_b^{5.9} \text{ (100 μm to 150 μm particle diameter)} \qquad \text{(B-2)}$$

---

(22) Woodruff, N. P., and F. H. Siddoway. A Wind Erosion Equation. Soil Science Proceedings, 29:602-608, May 1952.

(23) Bagnold, R. A. The Physics of Blown Sand and Desert Dunes. Metheun and Co., London, England, 1954. 265 pp.

(24) Shafer, H. J. A Model Study of the Reduction of Wind Transport of Fine Particles by Aerodynamic Barriers. Presented at the Fifth Annual Conference on Aviation and Astronautics, Tel Aviv and Haifa, Israel, 1963. pp. 57-63.

(25) Woodruff, N. P., and W. S. Chepil. Sedimentary Characteristics of Dust Storms II - Visibility and Dust Concentration. American Journal of Science, 2:104-114, February 1957.

(26) Cowherd, C., K. Axetell, Jr., and G. Jutze. Development of Emission Factors for Fugitive Dust Sources. EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1974. 172 pp.

Bulk density is an extremely important entrainment factor for free-flowing deposits because, at some critical wind velocity, dispersion may change from single particle to clump detachment. Dawes (21) reports an additional relationship for the effect of density on fine coal dust:

$$E_n \propto \rho_b^2 \text{ (particle size range unknown)} \qquad \text{(B-3)}$$

The relationship is dependent upon particle size and thus bulk density will reflect fineness of the coal dust.

c. Surface Area, s, (cm^2)

Due to a wide scattering of data, the investigators (20) derived no relationship between entrainment rate and dust bed surface area for free-flowing deposits. However, by employing a regression analysis on their data, the following approximate relationship was determined for free-flowing dust beds:

$$E_n \propto s^{0.345} \qquad \text{(B-4)}$$

d. Other Wind Tunnel Study Parameters

The parameters listed below were studied in a wind tunnel and no relationship was found (20). A regression analysis shows that their effect on emissions, if any, is not as pronounced as those of the other parameters. The height, volume, and possibly the leading angle may be expressed as functions of surface area:

Function	Relationship
Angle, deg.	$E_n \propto A_L^{0.149}$
Volume, cm	$E_n \propto V^{0.25}$
Height, cm	$E_n \propto H^{0.228}$
Width, cm	$E_n \propto W^{0.386}$

e. Nonwind Tunnel Study Parameters

A number of factors thought to influence open coal storage emissions were not considered in the aforementioned investigation. These factors include:

- Length of the coal pile along the prevailing wind direction (22)

- Particle-size distribution (22) (effects independent of bulk density)[a]
- Surface moisture (12, 22, 26, 27)

They were assessed in other studies, although the relationships derived were based on wind erosion of soil and windblown emissions from tailings and aggregate storage piles. The quantitative aspects of these factors relative to entrainment rates are discussed below.

(1) Length--

$$E_{SO} \propto f\ (L' - b)^n \quad \text{(Reference 22)} \qquad \text{(B-5)}$$

where L' = length of exposed field areas

This relationship may not be applicable to open coal storage due to the relatively small values for L' involved and the geometric differences between fields and storage piles. This function attempts to relate "avalanching" which generally is not precipitated in less than several hundred yards. Coal piles are usually not long enough for this to occur.

(2) Particle Size Distribution--

$$E_{SO} \propto I \quad \text{(Reference 22)} \qquad \text{(B-6)}$$

where I = the soil erodibility index for different soil fractions

This relationship may not be applicable to open coal storage in its present form due to physical and chemical dissimilarities between coal particles and soil fractions. Since this assessment is primarily concerned with respirable dust (<7 μm), the primary effect is described by bulk density and particle size is not deemed of further importance in the comparison of one coal pile to another.

(3) Moisture--

$$E_{SO} \propto \frac{1}{M^2} \quad \text{(Reference 22)} \qquad \text{(B-7)}$$

$$E_{SO} \propto \frac{1}{(P-E)^2} \quad \text{(References 12, 22)} \qquad \text{(B-8)}$$

where M = surface moisture

[a]Entrainment rate is a function of particle size and a function of bulk density; these are treated as two independent variables.

P-E, which refers to Thornthwaite's precipitation-evaporation index, is only an approximation of surface soil moisture and is used because values for M are not readily available.

$$E_{SO} \propto \frac{1}{(P-E)^2} \quad \text{(Reference 27)} \qquad \text{(B-9)}$$

(Here, E_{SO} refers to tailings piles rather than soil.)

$$E_A \propto \frac{1}{(P-E)^2} \quad \text{(Reference 26)} \qquad \text{(B-10)}$$

Of all these factors, surface moisture is most important since it will tend to suppress dust. The evaporation of moisture will likewise provide thermal currents which enhance dust formation. This action is similar to that occurring in soils and thus the P-E index as described by Thornthwaite, is a logical representation for surface moisture.

The empirical relationships shown here are for the most part very general approximations based on a variety of investigations. They may not be directly representative of conditions encountered in open coal storage. Thus, the accuracy and applicability of the results in the composite equation presented in the next section should be viewed with this in mind. Although quantitative relationships derived in this analysis may not be directly applicable to open coal storage, some conclusions concerning the relative importance of the various factors to coal dust entrainment are drawn by sensitivity analysis in Section 3.c. of this appendix.

3. COMPOSITE EQUATION

a. Development

Based on the relationships presented in Section 2 of this appendix, the following quantitative expressions are judged to be most applicable to open coal storage:

$$Q \propto u^{2.7-3.0} \qquad \text{(B-11)}$$

where u = wind velocity

$$Q \propto \rho_b^{\,2} \qquad \text{(B-12)}$$

where ρ_b = bulk density

---

(27) Jutze, G. A., K. Axetell, and W. Parker. Investigation of Fugitive Dust - Sources, Emissions, and Controls. EPA Contract 68-02-0044, Task 9, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, May 1973. 61 pp.

$$Q \propto H^{0.23} \tag{B-13}$$

where H = height

$$Q \propto A_L^{0.15} \tag{B-14}$$

where A_L = leading angle in the prevailing wind direction

$$Q \propto V^{0.25} \tag{B-15}$$

where V = volume

$$Q \propto s^{0.35} \tag{B-16}$$

where s = surface area

$$Q \propto (P-E)^{-2} \tag{B-17}$$

Obviously, wind velocity, bulk density, and surface moisture (P-E index) are the most important factors influencing the open coal storage entrainment/emission rate, Q.

The remaining variables: height, leading angle in the prevailing wind direction, volume, and surface area, describe coal pile geometry. Length and width, which also describe pile geometry, are deleted because they could not be adequately related to open storage entrainment; that is, they are not describable in a manner that would increase the usefulness of a quantitative expression. Judging by the similarity of the exponents attached to H, A_L, V, and s, the factors determing coal pile geometry are all interrelated. For this reason, a single variable, s, was chosen to describe pile geometry. Considering the small magnitude of the exponents attached to s, H, A_L, and V, entrainment rate is only slightly dependent on pile geometry. Based on these criteria, open coal storage entrainment is determined by the following expression:

$$Q = k \frac{u^a \rho_b^b s^c}{(P-E)^2} \tag{B-18}$$

where the exponents are expected to be in the range:

$$2.7 < a < 3.0$$

$$2 < b < 6$$

$$0.15 < c < 0.35$$

b. Comparison with Wind Erosion

Both Woodruff (22) and Chepil (25) have described the process of wind erosion and the factors which affect soil erosion. The Woodruff equation is of the form:

$$E = f(I', C', K', L', V') \quad \text{(B-19)}$$

where I' = soil and knoll erodibility index for different soil fractions
C' = local wind erosion climatic factor
K' = surface roughness
L' = unsheltered distance across the field along the prevailing wind direction
V' = vegetative cover
.E = potential average annual soil loss

This may be reduced to Equation B-20 by defining the variables through their appropriate algorithms. Thus:

$$E = I \cdot C \cdot K \cdot L \cdot V \quad \text{(B-20)}$$

where

$$I = f(I') \quad \text{(B-21)}$$

$$C = f(C') \quad \text{(B-22)}$$

$$K = f(K') \quad \text{(B-23)}$$

$$V = f(V') \quad \text{(B-24)}$$

$$L = f(L', I \cdot K, I \cdot C \cdot K) \quad \text{(B-25)}$$

This form of equation is the same as the process described by Woodruff and Siddoway (Equation B-19). Equations B-21, B-22, B-23, and B-24 are very direct relationships based completely upon independent variables which are not as complex for coal storage piles as they are for wind erosion.

Parameter I can be related to the particle size distribution of the material being eroded. Furthermore, this particle size distribution can be related to the bulk density of the coal in a direct manner. Thus, for a size distribution, SD,

$$I = k_1 (SD)^a = k_2 \rho_b{}^b \quad \text{(B-26)}$$

where

$$SD = k_3 \rho_b{}^{b/a} \quad \text{(B-27)}$$

or

$$SD \propto \rho_b{}^c \quad \text{(B-28)}$$

Equation B-26 gives a relationship of the basic erodibility for the source. As the particle size distribution range is reduced (from 840 μm to 7 μm), a smaller variation in I would be expected as one proceeds from site to site of a source. This has been borne out in the wind tunnel studies already completed on coal (20, 23).

The parameter C can be related wholly to the ratio of wind speed to P-E index:

$$C = k_4 \frac{u^3}{(P-E)^2} \tag{B-29}$$

The parameters K and V are related to ridge roughness and vegetation cover and for coal storage piles these can be equated to one since neither one is applicable.

The length of the unsheltered field is the only complex variable which need be addressed. In Woodruff's system, the effect can be described by Equations B-30, B-31 and B-32. Woodruff used E_2 equal to the product of I and K, so that E_2 may be set equal to I in these expressions.

$$L = 1.0 \tag{B-30}$$

when $$E_2 > 37.317\ (L')^{0.751} \tag{B-31}$$

Otherwise $$L = k_5\ (L')^e\ E_2{}^g \tag{B-32}$$

where L' = distance across field

Combining Equation B-20, B-26, B-29 and B-30, the overall expression for E can be described as:

$$E = k_2\ k_4 \frac{u^3\ \rho_b{}^b}{(P-E)^2} \tag{B-33}$$

Since Q is mass emission per unit time and E is mass erosion per area per unit time, Equation B-33 can be expressed:

$$Q = Es \tag{B-34}$$

$$Q = k_6 \frac{u^3 \rho_b{}^b s}{(P-E)^2} \tag{B-35}$$

where $k_6 = k_2 \cdot k_4$
s = area of pile

If Equation B-32 is used instead of Equation B-30, then the overall expression for E becomes Equation B-37 since I may be substituted for E_2 in Equation B-32 to yield Equation B-36. However, this can be further reduced to Equation B-38 with Equation B-26.

$$L = k_5 (L')^e I^g \tag{B-36}$$

$$E = k_2 k_4 k_5 \frac{u^3 \rho_b{}^b (L')^e I^g}{(P-E)^2} \tag{B-37}$$

$$E = k_2^{(1+g)} k_4 k_5 \frac{u^3 \rho_b{}^{(b+bg)} (L')^e}{(P-E)^2} \tag{B-38}$$

For this study, the length of the exposed field, L', used by Woodruff can be equated to a parameter of the coal pile. Assuming that coal piles are square with an area of s, Equation B-39 can be combined with Equation B-38 to give the net relationship shown in Equation B-40.

$$s = (L')^2 \tag{B-39}$$

$$E = k_7 \frac{u^3 \rho_b{}^m s^{e/2}}{(P-E)^2} \tag{B-40}$$

where

$$m = b + bg \tag{B-41}$$

$$k_7 = k_2^{(1+g)} k_4 k_5 \tag{B-42}$$

Substituting for E (from Equation B-40) into Equation B-34, the overall relationship is obtained:

$$Q = k_7 \frac{u^3 \rho_b{}^m s^n}{(P-E)^2} \tag{B-43}$$

where

$$n = \frac{e}{2} + 1 \tag{B-44}$$

Thus, either Equation B-35 or B-43 would describe the windblown emissions for coal piles depending upon the size of the pile. These equations compare favorably with the form of Equation B-18 and confirm the validity of the form of emission expression given.

By combining Equations B-31, B-39 and B-26, Equation B-35 may be considered valid when:

$$\rho_b > \left[\frac{37317}{k_2} \quad (s)^{0.375}\right]^{1/b} \qquad \text{(B-45)}$$

otherwise the expression developed in Equation B-43 would be valid. Thus, for large coal storage piles, the expression for Q in Equation B-43 could be most appropriate. A regression of the expression in Equation B-18 with sampling data would resolve the correct exponents.

c. Sensitivity Analysis

The factors which affect coal storage pile emissions can be considered as bounded variables. Thus the emission equation will likewise be a bounded expression. It is desired to express all results ultimately on an annual basis so that all factors should be annual mean values. The range of each of these factors is as follows:

$1.3 < u < 6.7$ m/s	average = 4.5 m/s
$0.64 < \rho_b < 0.86$ g/m^3	average = 0.80 g/m^3
$7 <$ P-E < 179	average = 91
$4.0 < s < 5.3 \times 10^5$ m^2	average = 4.0×10^4 m^2

By selecting exponents for Equation B-18 the effect of each variable can be determined. A value for the expression is determined from average values to serve as a reference. The results of the sensitivity analysis are given in Table B-1. It is apparent that P-E index is by far the most important factor affecting the distribution of emissions from coal piles. The least effect is from density. The omission of density from the expression would result in a possible variation in emissions of as much as ±65%. Leaving P-E index out gives an unreal variation of ±8,500. The factors which affect the emissions are (in decending order of importance) P-E index, wind speed, area, and density.

Since the P-E index affects the emissions the greatest, emissions can vary greatly with ambient temperature and precipitation. Without the effect of P-E index, emissions could vary by 350%; however, the normal variation in precipitation can exceed this in most parts of the U.S. Coupled with this is the normal fluctuation in ambient temperature at a specific site. Thus the variation in emission rate of a coal pile is greater at a specific site than it normally would be from one site to another.

4. SUMMARY

Equation B-18 is used in conjunction with the sampling results in Appendix A (Table A-2) to determine an analytical expression or the emission rate from coal storage piles (Equation A-5) which is reproduced as follows:

TABLE B-1. SENSITIVITY ANALYSIS OF ENTRAINMENT/EMISSION RATES CALCULATED USING EQUATION B-18[a] WITH AVERAGE, MINIMUM, AND MAXIMUM VALUES FOR WIND VELOCITY, BULK DENSITY, P-E INDEX, AND SURFACE AREA

Exponents[a]			Entrainment/emission rate (Q) (Calculated using average, minimum or maximum values for independent variables as indicated)									
			Using average values for all variables[b]	Wind speed, m/s		Bulk density, g/cm^3		P-E index		Surface area, m^2		
a	b	c		u = 1.3	u = 6.7	ρ_b = 0.64	ρ_b = 0.86	P-E = 7	P-E = 179	s = 4.0	s = 5.3 x 10^5	
3.0	2.0	0.35	97	2.3	319	62	112	16,300	25	3.8	239	
				Δ^c = 3.3		Δ = 0.52		Δ = 170		Δ = 2.4		
3.0	6.0	0.35	40	0.95	131	10.4	62	6,680	10.2	1.6	98	
				Δ = 3.2		Δ = 1.3		Δ = 170		Δ = 2.4		
2.7	2.0	0.35	61	2.2	180	39	71	10,400	15.9	2.4	152	
				Δ = 2.9		Δ = 0.82		Δ = 170		Δ = 2.4		
3.0	2.0	0.15	12	0.28	38	7.4	13.4	1,960	3.0	5.7	17	
				Δ = 3.1		Δ = 0.50		Δ = 160		Δ = 0.94		

[a] Equation B-18:

$$Q = \frac{k u^a (\rho_b)^b s^c}{(P\text{-}E)^2}$$

where Q = entrainment/emission rate, mg/s
k = constant = 336
u = wind velocity, m/s
ρ_b = bulk density, g/cm^3
s = surface area, m^2
a,b,c = exponents
P-E = Precipitation-Evaporation Index

[b] Average values for independent variables:

u = 4.5 m/s
ρ_b = 0.80 g/m^3
s = 4.0 x 10^4 m^2
P-E = 91

[c] Δ is calculated from:

$$\frac{Q_{max} - Q_{min}}{Q_{avg}}$$

where Q_{max} = emission rate calculated using maximum values for independent variable

Q_{min} = emission rate calculated using minimum value for independent variable

Q_{avg} = emission rate calculated using average values for all independent variables

$$Q = 336 \frac{u^3 \rho_b^2 s^{0.345}}{(P-E)^2} \qquad \text{(B-46)}$$

This expression can be used to predict emissions within 124%, 95% of the time over limited ranges of u, ρ_b, s and (P-E) as described in Appendix A. Since this expression has limited use and it was not desired to pursue its development into a more universal equation, only its implications on the factors affecting emissions are used in this document. For relating emissions to these parameters an overall emission factor is used.

APPENDIX C

DERIVATION OF SURFACE AREA FROM HEIGHT OF COAL PILES

The surface area of a coal storage pile is primarily a function of the amount of coal stored. Functionally, this is determined as follows:

$$s = \frac{T_c}{\rho_b H} \qquad \text{(C-1)}$$

where s = surface area, cm^2
T_c = weight of coal stored, g
ρ_b = bulk density, g/cm^3
H = pile height, cm

In the mass emission rate equation developed in Appendix B, s is used to relate all geometric parameters of coal piles. This assumes a dependence on the height of the coal pile. It has been stated that coal is generally piled 4.3 m to 8.8 m (14 ft to 29 ft) high, averaging about 5.8 m (19 ft) (28). A random survey was conducted of 12 coal piles. The results, given in Table C-1, indicate a range of 2.4 m to 11.3 m (8 ft to 37 ft), with the average being 6.0 m (19.6 ft) which is within 3% of the reported data. For converting weight to surface area, a constant height of 5.8 m (19 ft) is used.

Pile shape, and thus height, is generally dependent on the weight of coal stored. The small piles usually associated with smaller boilers or coke plants are generally conical in form to facilitate handling. Conical storage does not require the use of auxiliary equipment such as bulldozers. In addition, the smaller plants are usually nearer to population centers, and space is at a premium.

---

(28) Annual Report of Research and Technologic Work on Coal. Bureau of Mines IC-7518, U.S. Department of the Interior, Washington, D.C., 1949. p. 39.

TABLE C-1. HEIGHT OF COAL PILES

Site	Height m	Height ft
1	7.6	25
2	6.1	20
3	4.3	14
4	6.1	20
5	9.1	30
6	3.0	10
7	11	37
8	8.2	27
9	3.6	12
10	6.1	20
11	3.6	12
12	2.4	8

$\bar{x}$ = 6.0 m or 19.6 ft

The error in predicting the supply stored varies with the facility at which the coal is stored. For the three types of facilities considered, the errors are:

Coke plants	23 days ± 43%
Boiler plants	39 days ± 59%
Utilities	93 days ± 74%

Based on the number of each type of facility, the overall weighted error introduced due to normal variations of tonnage stored is 61%. The use of 800 kg/m^3 (50 lb/ft^3) for the density of coal introduces an additional error of 10%. By considering the coal pile height constant at 5.8 m (19 ft), the error is 26%. Thus the error introduced by the use of constant values for ρ_b and H increases the error in the estimate of s by 36%. The overall error is 97% which is within the allowable limits for use in the emission rate equation (Appendix B).

APPENDIX D

SAMPLING EQUIPMENT AND PROCEDURES

1. HIGH-VOLUME SAMPLING METHODS AND EQUIPMENT

To perform the sampling required, high-volume samplers[a] were positioned around the coal pile as shown in Figure A-1 and A-2. The arrangement in Figure A-1 permitted correlation with horizontal dispersion and sampler S_3 would illustrate downwind power law decay. This arrangement was altered for later sampling to Figure A-2 when the observed concentrations were not sufficient to make these correlations. Nucleopore® membrane filters were used for sample collection due to their relatively low tare weight (500 mg) and high flow capacity (36 l/min-cm^2, 93.3 kPa pressure drop) in comparison with similar filters. The lower tare weight and higher flow capacity enabled the particulate collected to comprise a higher percentage of tare weight and thus provide results that were within the measurable range. After particulate matter on the filters was weighed (subtracting the tare weight), the mass concentration of suspended particulate was computed from the volume of air sampled. The concentration of particulate collected at reference sampler S_0 was subtracted from the concentration of the other samplers (S_1, S_2, S_3, and S_4) to yield the particulate concentration due to the coal pile emissions. The mass emission rate was determined using Turner's equation for a ground level source with no effective plume rise (16) as shown in Appendix A.

A Brink® impactor was used to determine the size distribution of the particles emitted. This unit has a relatively low sampling rate of $\leq 5 \times 10^{-5}$ m^3/s ($\leq$0.1 acfm) and small tare weight ($\approx$13 mg) in comparison with similar units. The percent of particles smaller than 5 μm captured by the Brink unit was used to estimate the weight of respirable particulates collected by the high volume samplers. Because of the low mass emission rate only one composite sample (two sample days) was collected.

A meteorological station was employed to monitor wind speed, direction, and temperature. The median wind speed over a 1-minute time lapse, was recorded at 15-minute intervals. The mean wind speed was then calculated from the arithmetic average of the

---

[a]General Metals Works, Inc., Cleves, Ohio.

15-minute readings over the entire run. Wind direction was similarly recorded every 15 minutes. If the direction varied by more than ± 0.78 rad (± 45°) from the centerline for two consecutive recordings, then either: 1) sampling was terminated when the runs had proceeded for more than 4 hours, or 2) sampling was continued when the wind direction returned to within ± 0.78 rad (± 45°) if the run had proceeded for less than 4 hours. The standard of 4 hours was chosen since it is approximately the minimum time required for particulate collection to equal about 20% of the tare weight of the filter, the target minimum weight of collected particulate that can be measured. The minimum desired mass of particulate collected is a weight equal to one-half the tare weight of the filters. A sampling run of 8 hours was chosen in an attempt to achieve this goal. The ± 0.78 rad (± 45°) (from centerline) fluctuation of wind direction between two consecutive runs was chosen since greater variations have resulted in poor particulate collection. Quite often, changes of this magnitude result in frontal movement and rain or wind storms.

Temperature values were read at the meteorological station within the accuracy of the instrument, which was ± 1.1°C (± 2°F), and averaged for the week of sampling. Precipitation levels for the week were obtained from the nearest weather bureau in the area. Weekly values are utilized to determine the possible effect of these parameters prior to sampling. These effects are then accounted for by calculating a psuedo P-E index for the year from these weekly values. (A yearly index based upon weekly values, assumes that sample history for every week is identical to each and every other week, that is, the rain and temperature patterns are identical, for the year, to the selected weeks.)

To determine the quantity of coal stored, the present inventory level at the plant was obtained from company records. Bulk density was obtained directly from tables relating density to the class of coal stored or from proximate analysis (supplied by the company).

2. FILTER ANALYSIS PROCEDURES

a. Concentrations

High volume samplers are used to collect the particulate matter. Weights are determined to the nearest milligram, airflow rates to the nearest 5×10^{-3} m^3/s, and time to the nearest 5 minutes. Mass concentrations are reported to the nearest $\mu g/m^3$. At an average mass concentration of 128 $\mu g/m^3$, the standard deviation is 5.12.

Prior to sampling the unit was calibrated by use of a calibrating orifice assembly and water manometer. (These calibration units

are adjusted with a positive displacement meter.) A chart was then drawn of airflow versus static pressure. After the orifice was attached to the unit the airflow was varied by the addition of perforated plates across the airflow stream. A calibration curve was then plotted relating airflow readings to actual flow in non-metric units.

Prior to sampling, each filter was inspected for imperfections, desiccated in a balance room, and weighed to the nearest milligram in a weighing chamber. The tare weight was then recorded and the filter holder labeled. Once sampling was completed, the volume was determined from the initial and final airflow readings. (These readings are converted to m/min through an appropriate calibration curve.) The volume of air sampled was determined as follows:

$$V_a = \frac{(Q_i + Q_f) \times t_s}{2} \qquad \text{(D-1)}$$

where V_a = air volume sampled, m^3
Q_i = initial airflow rate, m^3/min
Q_f = final airflow rate, m^3/min
t_s = sampling time, min

Once the volume was determined and the final weight of the filters established (by the procedure previously mentioned), the mass concentration of particulates was determined by:

$$X = \frac{(W_f - W_i) \times 10^6}{V_a} \qquad \text{(D-2)}$$

where X = mass concentration of particulate, $\mu g/m^3$
W_i = initial (tare) weight of filter, g
W_f = final weight of filter, g
V_a = volume of air sampled, m^3
10^6 = conversion of g to μg

b. Composition

After the filter is weighed, one portion is selected for microscopy examination and another for composition analysis. X-ray fluorescence was chosen to give a semiquantitative determination of particulate composition.

(1) The Principle of X-Ray Fluorescence (XRF) Analysis--
XRF analysis is based on measuring individual, characteristic x-rays for each element in a sample by energy dispersive techniques. These secondary fluorescent x-rays are generated by irradiating the specimen with a primary source of x-rays using either a tungsten or rhodium target x-ray tube. All secondary x-rays are detected simultaneously with a silicon semiconductor detector. By using suitable amplifiers and an x-ray energy distribution analyzer, the characteristic x-rays for each element

are electronically separated based on their energy and are displayed in either a spectral or alphanumeric mode via video monitor. The data are also stored in a computer memory for additional data improvement or for on-line computerized data reduction and presentation in a teletype print-out.

An on-line computer is used for data reduction. Computer programs enable manipulation of spectral data to eliminate interfering lines, to integrate peaks, to subtract backgrounds, to correct for interelement and matrix effects, and to provide a variety of quantitative conversion equations to reduce raw counts to elemental concentration.

(2) Applicability of XRF--
The XRF technique is applicable to qualitative and quantitative elemental analyses (sodium to uranium) for solids (whole sections or powdered) and liquids (including solids in solution). In the specific case of particulate collected on filters, the direct measurement of these specimens can provide a detection limit of <0.2 $\mu g/cm^2$ with sample loadings of 1.2 $\mu g/cm^2$. The detection limit is influenced by many factors including energy of the x-rays being emitted by the elements, matrix, counting times, excitation source, and sample chamber atmosphere. For particulate on filter paper with a loading of 1.2 $\mu g/cm^2$ and with a rhodium excitation source, the following detection levels can be attained:

Element	Detection level, $\mu g/cm^2$
P	0.20
S	0.11
K	0.15
Ca	0.06
Cr	0.06
Fe	0.05
Ni	0.05
Cu	0.05
Zn	0.04
As	0.04
Br	0.07
Cd	0.13
Ba	0.13
Hg	0.08
Pb	0.07

(3) XRF Apparatus--
The analytical system used in these measurements is composed of an EDAX International Inc. Mark II Basic EDAM System, EDAX Model 707A Super Analyzing Unit, a Data General Corp. 12 K Computer (Nova 1220), and a Teletype 33TC. Either a rhodium or tungsten target x-ray tube is available. The system can be operated with

the sample maintained in vacuum or in a helium purged atmosphere. Samples up to 76 mm (3 in.) in diameter can be analyzed.

(4) Calibration of XRF Equipment--
Quantitative analysis with the x-ray technique is based on using (a) reference standards of known concentrations of the desired elements in a matrix similar to that of the unknown specimens, or (b) mathematical corrections through computer programs to correct for interelement and matrix effects.

If a range of standards is avilable, it is possible to establish a working curve for each element which is a plot of concentrations in micrograms (or $\mu g/cm^2$) vs. the intensity of the x-rays characteristic of each element. If the range of standards is not available, the ratio of the intensity of the peak of unknown concentration of an element to the intensity of the peak of a known concentration of that same element will provide a reliable semiquantitative analysis ($\pm \leq 50\%$ of the amount present).

Standards are prepared by precipitation or deposition of NBS Standard Research Materials, metal oxides or salts, or portions of "loose" particulate collected during long-term sampling. In the latter case, emission spectrographic analysis of this material serves to provide the needed compositional information for preparing standards. Several deposition procedures are used for preparing semiquantitative standards including the filtration of particulate suspended in carbon tetrachloride and the filtrations of particulate suspended in gas matrix or deposited from solution.

Other semiquantitative measurements of particulate collected on filters are made by correlating the x-ray fluorescence responses of test samples with emission spectrographic analyses of ash for one or more of the test specimens in a set. This correlation serves to provide a semiquantitative means of rapidly analyzing large numbers of filters by XRF without going through an ashing step, which is required for emission spectrographic analyses of filters with low loadings.

(5) Procedure for XRF Analysis--
Based on the type of sample matrix and the elements being measured, the excitation source and the x-ray excitation voltage are selected. Either a helium flush or vacuum is applied to the sample chamber, and proper selection of the energy range is made to optimize response. The filter specimen is analyzed by counting the secondary x-rays for 100 seconds to 2,000 seconds depending on quantity of material on the filter.

The spectral data are manipulated by computer software to smooth the statistical channel-to-channel fluctuations in the spectrum, subtract background or spectra characteristic of residual trace elements in the filter, strip a series of peaks characteristic of specific elements, and obtain quantitative or semiquantitative

data by comparing the spectral intensity of the test specimen with the known values of the standard samples.

(6) Calculations--
The computer provides the resulting values (quantitative or semi-quantitative) in $\mu g/cm^2$ or comparable notation as programmed.

3. GAS SAMPLE ANALYSIS

a. Collection Procedure

Several grab samples were collected for analysis of total hydrocarbons, methane, carbon monoxide and total sulfur. A 250-ml Pyrex flask with a stopcock on each end was cleaned and filled with dry nitrogen. The top of one of the stopcocks was fitted with a rubber bulb and one-way flow valve so as to pull a vacuum on the Pyrex flask. The other stopcock was covered with cotton and inserted about 150 mm into the coal pile. Both stopcocks were then opened and about 1 liter of gas was pulled through the flask. The stopcocks were closed and the flask returned to the laboratory for analysis.

b. Analysis of Total Hydrocarbons, Methane and Carbon Monoxide

(1) Principle and Applicability--
The method used in this analysis is a semicontinuous technique for measuring total hydrocarbons, methane and carbon monoxide in ambient air (29). Minor modification of electronics enables measurements from 0.1 ppm up to 2%.

(a) Principle--Measured volumes of gas samples are delivered to a hydrogen flame ionization detector to measure total hydrocarbon content. An aliquot of the same gas sample is introduced into a stripper column which removes water, carbon dioxide, and hydrocarbons other than methane. Methane and carbon monoxide are passed quantitatively to a gas chromatographic column where they are separated. The methane is eluted first and is passed unchanged through a catalytic (nickel) reduction tube into the flame ionization detector. The carbon monoxide is eluted into the catalytic reduction tube where it is reduced to methane before passing through the flame ionization detector. Between analyses, the stripper column is backflushed to prepare it for the subsequent analysis. Hydrocarbon concentrations corrected for methane are determined by subtracting the methane value from the total hydrocarbon value.

(b) Applicability--The method is applicable to the semicontinuous measurement of hydrocarbons, methane, and carbon monoxide in ambient air and in grab samples from emission sources.

---

(29) Federal Register, 36(228), November 25, 1971.

(2) Apparatus--
The instrument was designed and assembled by Monsanto Research Corporation personnel using design criteria that met Federal EPA specifications. Another model in this series was tested and found acceptable by the Federal EPA at Research Triangle Park, North Carolina.

(3) Calibration--
The instrument is calibrated with a series of methane and carbon monoxide standards prepared in synthetic air by Scott Research Labs. The values of instrument response vs. concentration of the standard gas samples are plotted.

(4) Procedure--
The sample is introduced into the system under the same conditions of pressure and flow rates as are used in calibration. Mathematical corrections can be made as needed for sample pressure differences (particularly when analyzing glass gas sampling tubes) by incorporating suitable pressure-volume relationships based on the ideal gas law.

(5) Calculations--
Concentrations of total hydrocarbons (as methane equivalents), methane, and carbon monoxide are determined directly from the calibration curves. No calculations are necessary, unless sample-standard pressure differences require corrections [see (4) above]. The concentrations of hydrocarbons corrected for methane is obtained by subtracting the methane concentrations from the total hydrocarbon concentration (as CH_4).

c. Analysis of Sulfur

Several methods for sulfur analysis were attempted. Flame photometric and gas chromatographic analyses did not indicate substantial levels of any sulfur compounds even upon heating of the sample flask. The lower level of detection was 0.1 ppm. A variety of other procedures was also briefly investigated.

4. SAMPLING GUIDELINES AND DATA SHEETS

Guidelines and sampling data sheets used by field sampling teams for open sources are shown in Tables D-1, D-2, and D-3, and Figure D-1.

TABLE D-1. OPEN SOURCES SAMPLING GUIDELINES

1. Determine predicted wind direction and speed

   a. U.S. Weather Bureau

   b. Field estimate

2. Determine atmospheric stability class expected - see Table on worksheet, (Figure D-1).

3. Locate positions of samplers around source. Use guidelines for downwind distance (Table D-2).

4. Place upwind sampler (background) and start sampling.

5. Place wind instrument and downwind samplers for source monitoring.

6. Wind direction and speed monitored every 15 minutes, stability class every 2-3 hours, note time sampler flow rates were checked at first 1/2 hour and then every 1-1/2 hours. If wind direction is off centerline by more than 0.78 rad (45°) in two consecutive readings, stop samplers until direction returns within 0.78 rad (45°) for 15 minutes.

7. Sampling completed in minimum sampling time determined by project leader.

TABLE D-2 PLACEMENT OF SAMPLES DOWNWIND OF OBSTRUCTIONS

1. Both the open source height and the obstructions must meet the required minimum distance criteria.

2. Stability class is determined from cloud cover, wind speed, and time of day.

3. The height of obstruction or source equals H.

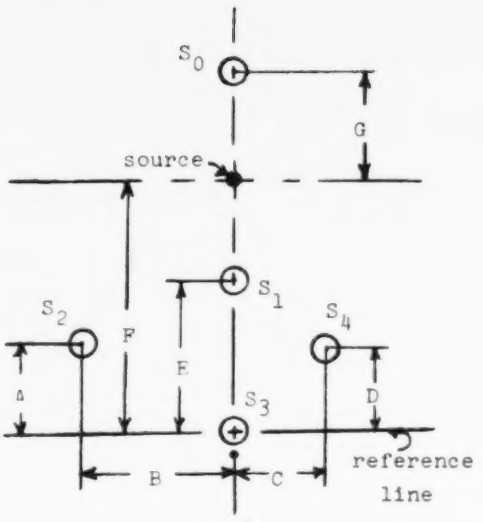
Stability Class	Minimum distance downwind from obstruction peak
A	5H
B	7H
C	10H
D	17H
E	25H[a]
Other classes	Cannot be done

[a] Requires an additional sampler at least 15H downwind for backup.

TABLE D-3. FUGITIVE DUST SAMPLER AND METEOROLOGICAL DATA LOG

Date_____ Run_____ Page_____

Time (24 hr. clock)	Wind Speed mph		Wind Direction Compass degrees		S_1		S_2		S_3		S_4		Other comments
	avg.	range	avg.	range	Roto cfm	Act cfm	Roto cfm	Act cfm	Roto cfm	Act cfm	Roto cfm	Act cfm	
Totals													
Average													
Total elapsed time													Sampling crew

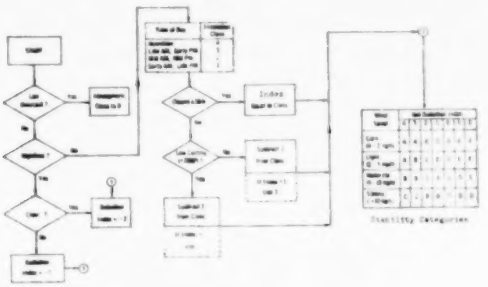


Run No. _____
DATE _____

actual barometric pressure _____ "Hg

dry bulb	_____ °F	_____ °F
wet bulb	_____ °F	_____ °F

ATMOSPHERIC STABILITY DETERMINATION



A	_____ ft. (measured)		
B	_____ ft. "		
C	_____ ft. "		
D	_____ ft. "		
E	_____ ft. "		
F	_____ ft. (estimated)		
G	_____ ft. "		

TIME	_____	STABILITY	_____
"	_____	"	_____
"	_____	"	_____
"	_____	"	_____

COMMENTS:

Sampler	Filter No.
S_0	_____
S_1	_____
S_2	_____
S_3	_____
S_4	_____

Brinks sampler located next to S_1
wind instrument is behind S_3
obtain sample of source before signing sheet

Sampling crew _____
_____
_____

Figure D-1. Fugitive dust sampling worksheet.

APPENDIX E

COMPUTATION OF COMBINED ERRORS

The value of emission rate, Q, is determined in the field by application of Gaussian dispersion equations to the concentrations obtained at high volume samplers. These emission values have a standard deviation which is a function of the standard deviation of the variables. The emission rate is calculated using Turner's (14) estimates of atmospheric dispersion from ambient measurement of χ. In such estimates, there is an error due to inconsistent airflow rates and there are errors in time measurements and weighing which are part of the emission error.

The values of atmospheric stability as reflected by the standard deviations (σ) in the horizontal and vertical planes are valid for a sampling time of 10 minutes. The vertical deviation is expected (14) to be correct within a factor of 2 for: 1) all stabilities out to a few hundred meters, and 2) neutral to moderately unstable conditions in the lower 1,000 meters of the atmosphere with a marked inversion above for distances out to 10 kilometers or more. Since all sampling was performed within a few hundred meters of the coal pile, these conditions were met. The estimate of horizontal dispersion, σ_y, will be less uncertain than that of σ_z. The emission determined will therefore be (for the three cases cited) within a factor of 3 for variations of σ_y, σ_z and u (14). Hence, the overall standard deviation in determining emission rate can be estimated as follows:

$$\sigma = \sqrt{(\sigma_1)^2 + (\sigma_2)^2} \qquad \text{(E-1)}$$

where σ_1 = estimated population standard deviation from sampling for χ

σ_2 = additional standard deviation in calculation of Q from χ

A factor of 3 is defined as follows:

$$\frac{X + \sigma_2}{X - \sigma_2} = 3 \qquad \text{(E-2)}$$

where X = any average value calculated or measured.

From Equation E-2, a factor of three in the calculation of Q implies

$$\sigma_2 = 0.5X \qquad \text{(E-2)}$$

Example 1

$$X = 6.4 \text{ mg/kg-yr}$$

and

$$\sigma_1 = 2.9 \text{ mg/kg-yr}$$

Hence,

$$\sigma_2 = 0.5\ (6.4) = 3.2 \text{ mg/kg-yr}$$

and

$$\sigma = \sqrt{(2.9)^2 + (3.2)^2} = 4.3 \text{ mg/kg-yr}$$

Example 2

$$X = 336 \text{ mg/kg-yr}$$

and

$$\sigma_1 = 200 \text{ mg/kg-yr}$$

Hence,

$$\sigma_2 = 0.5\ (336) = 168 \text{ mg/kg-yr}$$

then

$$\sigma = \sqrt{(200)^2 + (168)^2} = 261 \text{ mg/kg-yr}$$

APPENDIX F

DETERMINATION OF DISTANCE TO PLANT BOUNDARY AND POPULATION DENSITY FOR REPRESENTATIVE COAL STORAGE PILE

A survey was conducted of the same 12 sites used to determine pile height (Appendix C). These sites were originally selected at random and cover the spectrum of coal storage users as shown in Table F-1. Values which are three standard deviations beyond the mean were discarded to achieve the means presented. Since this would normally bias the results, deviations were discarded in pairs (a high and a low).

TABLE F-1. DISTANCE TO PLANT BOUNDARY AND POPULATION DENSITY FOR REPRESENTATIVE COAL STORAGE PILE

Site	Coal pile size, tons	Distance to boundary, ft	Population density, persons/mile^2
1	3,000	440	52
2	73,000	150	1,060
3	63,700	200	63
4	42,000	50	58
5	461,000	500	3
6	280,000	300	1
7	11,000	50	10
8	50,000	800	68
9	584,000	2,600	417
10	45,000	150	42
11	4,000	10	78
12	3,000	175	4
Mean (biased)	135,000	288	155
Standard deviation	198,000	236	306
Mean (metric units)	122 x 10^3 metric tons	86 m	61 persons/km^2

APPENDIX G

ANALYSIS OF COAL STORAGE PILES FOR POLYCYCLIC ORGANIC MATERIALS

Two samples from coal storage piles were selected for analysis of polycyclic organic materials (POM') by chemical ionization mass spectroscopy. The results are shown in Table G-1. The first sample was from a coal storage pile at an open pit mine where the coal had been aged for about 10 days at the most. The coal seam where this coal originated is typical of western subbituminous coal. The second sample is from an Indiana coal seam and is typical of interior region bituminous coal. This sample had aged for approximately 60 days and shows measurable quantities of benzo(c)phenanthrene, benzo(a)pyrene and 3-methylcholanthrene.

From Appendix A the average emission rate is 19 mg/s from coal storage piles. Taking an order of magnitude rise in a POM concentration (to account for unknowns) to 5 μg/g of coal, the emission rate (Q) for POM's would be 0.0095 μg/s. Severity is calculated using the noncriteria formula developed in Appendix H shown as follows:

$$S = \frac{316\ Q}{(TLV)\ D^{1.814}} \qquad (G\text{-}1)$$

For the POM calculation, the minimum representative distance (D) is 83 m and the TLV is 1 $\mu g/m^3$. Thus, the severity is 0.0099 for a representative coal pile which is two orders of magnitude below the severity for coal dust.

TABLE G-1. ANALYSIS OF COAL SAMPLES EXTRACTED WITH PENTANE FOR SELECTED POLYCYCLIC ORGANIC MATERIALS (POM'S) BY CHEMICAL IONIZATION MASS SPECTROSCOPY

Polycyclic organic material	Concentration, ppm (w/w)[a]	
	Open pit mine coal storage	Indiana coal storage[b]
Benzo(c)phenanthrene	ND (<0.2)	0.5 ± 0.1
7,12-Dimethylbenz(a)anthracene	ND (<0.2)	<0.2
Benzo(a)pyrene	∿0.2	0.3 ± 0.1
3-Methylcholanthrene	<0.2	0.4 ± 0.1
Dibenz(a,h)anthracene	ND (<0.2)	ND (<0.2)
Dibenzo(c,g)carbazole	ND (<0.2)	ND (<0.2)
Dibenzo(a,h)pyrene	ND(<2)	ND (<2)
Dibenzo(a,i)pyrene	ND(<2)	ND (<2)

[a] No signal was detected for the molecular weight plus one atomic mass unit ions of these compounds at their respective retention times.

[b] Unidentified peaks which eluted prior to the appearance of the first polycyclic organic compound listed above were present in this sample.

APPENDIX H

DERIVATION OF SOURCE SEVERITY EQUATIONS

1. SUMMARY OF MAXIMUM SEVERITY EQUATIONS

The maximum severity of pollutants may be calculated using the mass emission rate, Q, the height of the emissions, h, or the distance from the source to the nearest plant boundary, D, and the threshold limit value, TLV. The equations summarized in Table H-1 are developed in detail in this appendix.

2. DERIVATION OF χ_{max} FOR USE WITH U.S. AVERAGE CONDITIONS

The most widely accepted formula for predicting downwind ground level concentrations from a point source is (14);

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right] \qquad \text{(H-1)}$$

where χ = downwind ground level concentration at reference coordinate x and y with emission height of h, g/m^3
Q = mass emission rate, g/s
σ_y = standard deviation of horizontal dispersion
σ_z = standard deviation of vertical dispersion
u = wind speed, m/s
y = horizontal distance from centerline of dispersion, m
h = height of emission release, m
x = downwind dispersion distance from source of emission release, m
π = 3.1416

TABLE H-1. POLLUTANT SEVERITY EQUATIONS

Pollutant	Severity equation
For elevated sources:	
Particulate	$\frac{70\ Q}{h^2}$
SO_x	$\frac{50\ Q}{h^2}$
NO_x	$\frac{315\ Q}{h^{2.1}}$
Hydrocarbons	$\frac{162\ Q}{h^2}$
Carbon monoxide	$\frac{0.78\ Q}{h^2}$
Other	$\frac{5.5\ Q}{TLV \cdot h^2}$
For ground level sources:	
Particulate	$\frac{4,020\ Q}{D^{1.81}}$
SO_x	$\frac{2,870\ Q}{D^{1.81}}$
NO_x	$\frac{22,200\ Q}{D^{1.90}}$
Hydrocarbons	$\frac{9,340\ Q}{D^{1.81}}$
Carbon monoxide	$\frac{44.8\ Q}{D^{1.81}}$
Other	$\frac{316\ Q}{TLV \cdot D^{1.81}}$

We assume that χ_{max} occurs when $x >> 0$ and $y = 0$. For a given stability class, standard deviations of horizontal and vertical dispersion have often been expressed as a function of downwind distance by power law relationships as follows (30):

$$\sigma_y = ax^b \qquad \text{(H-2)}$$

$$\sigma_z = cx^d + f \qquad \text{(H-3)}$$

Values for a, b, c, d and f are given in Tables H-2 and H-3 (31). Substituting these general equations into Equation H-1 yields:

$$\chi = \frac{Q}{ac\pi ux^{b+d} + a\pi ufx^b} \exp\left[-\frac{h^2}{2(cx^d + f)^2}\right] \qquad \text{(H-4)}$$

Assuming that χ_{max} occurs at $x < 100$ m or the stability class is C, then $f = 0$ and Equation H-4 becomes:

$$\chi = \frac{Q}{ac\pi ux^{b+d}} \exp\left[\frac{-h^2}{2c^2x^{2d}}\right] \qquad \text{(H-5)}$$

For convenience, let:

$$A_R = \frac{Q}{ac\pi u} \text{ and } B_R = \frac{-h^2}{2c^2}$$

so that Equation H-5 reduces to:

$$\chi = A_R x^{-(b+d)} \exp\left[\frac{B_R}{x^{2d}}\right] \qquad \text{(H-6)}$$

---

(30) Martin, D. O., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at the 61st Annual Meeting of the Air Pollution Control Association, St. Paul, Minnesota, June 23-27, 1968. 18 pp.

(31) Tadmor, J., and Y. Gur. Analytical Expressions for the Vertical and Lateral Dispersion Coefficients in Atmospheric Diffusion. Atmospheric Environment, 3(6):688-689, 1969.

TABLE H-2. VALUES OF a FOR THE COMPUTATION OF σ_y[a] (31)

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

[a]For the equation

$$\sigma_y = ax^b$$

where x = downwind distance
b = 0.9031

TABLE H-3. VALUES OF THE CONSTANTS USED TO ESTIMATE VERTICAL DISPERSION[a] (31)

Usable range, m	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100 to 1,000	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	
<100	A	0.192	0.936	
	B	0.156	0.922	
	C	0.116	0.905	
	D	0.079	0.881	
	E	0.063	0.871	
	F	0.053	0.814	

[a]For the equation

$$\sigma_z = cx^d + f$$

Taking the first derivative of Equation H-6

$$\frac{d\chi}{dx} = A_R \left\{ x^{-b-d} \left(\exp \left[B_R x^{-2d} \right] \right) \left(-2dB_R x^{-2d-1} \right) + \exp \left[B_R x^{-2d} \right] \left(-b-d \right) x^{-b-d-1} \right\} \quad \text{(H-7)}$$

and setting this equal to zero (to determine the roots which give the minimum and maximum conditions of χ with respect to x) yields:

$$\frac{d\chi}{dx} = 0 = A_R x^{-b-d-1} \left(\exp \left[B_R x^{-2d} \right] \right) \left[-2dB_R x^{-2d-b-d} \right] \quad \text{(H-8)}$$

Since we define that $x \neq 0$ or ∞ at χ_{max}, the following expression must be equal to 0:

$$-2dB_R x^{-2d-d-b} = 0 \quad \text{(H-9)}$$

or

$$\left(b+d \right) x^{2d} = -2dB \quad \text{(H-10)}$$

or

$$x^{2d} = \frac{-2dB_R}{b+d} = \frac{2d\ h^2}{2c^2 (b+d)} \quad \text{(H-11)}$$

or

$$x^{2d} = \frac{d\ h^2}{c^2 (b+d)} \quad \text{(H-12)}$$

or

$$x = \left(\frac{d\ h^2}{c^2 (b+d)} \right)^{\frac{1}{2d}} \text{ at } \chi_{max} \quad \text{(H-13)}$$

Thus Equations H-2 and H-3 become:

$$\sigma_y = a \left(\frac{d\ h^2}{c^2 (d+b)} \right)^{\frac{b}{2d}} \quad \text{(H-14)}$$

$$\sigma_z = c\left(\frac{d\ h^2}{c^2\,(b+d)}\right)^{\frac{d}{2d}} = \left(\frac{d\ h^2}{b+d}\right)^{\frac{1}{2}} \qquad \text{(H-15)}$$

The maximum will be determined for U.S. average conditions of stability. According to Gifford (32), this is when $\sigma_y = \sigma_z$.

Since b = 0.9031, and upon inspection of Table H-2 (31) under U.S. average conditions, $\sigma_y = \sigma_z$, it can be seen that $0.881 \leq d \leq 0.905$ (class C stability[a]). Thus, it can be assumed that b is nearly equal to d or:

$$\sigma_z = \frac{h}{\sqrt{2}} \qquad \text{(H-16)}$$

and

$$\sigma_y = \frac{a}{c}\,\frac{h}{\sqrt{2}} \qquad \text{(H-17)}$$

Under U.S. average conditions, $\sigma_y = \sigma_z$ and $a \simeq c$ if $b \simeq d$ and f = 0 (between class C and D, but closer to belonging in class C).

Then

$$\sigma_y = \frac{h}{\sqrt{2}} \qquad \text{(H-18)}$$

Substituting for σ_y and σ_z into Equation H-1 and letting y = 0:

$$\chi_{max} = \frac{2\ Q}{\pi u h^2} \exp\left[-\frac{1}{2}\left(\frac{h\sqrt{2}}{h}\right)^2\right] \qquad \text{(H-19)}$$

or

$$\chi_{max} = \frac{2\ Q}{\pi e u h^2} \qquad \text{(H-20)}$$

---

[a] The values given in Table H-3 are mean values for stability class. Class C stability describes these coefficients and exponents, only within about a factor of two (14).

- - - - - - - - - -

(32) Gifford, F. A., Jr. An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Chapter 3, D. A. Slade, ed. Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 113.

For ground level sources (h = 0), χ_{max} occurs by definition at the nearest plant boundary or public access. Since this occurs when y = 0, Equation H-1 becomes:

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z u} \qquad \text{(H-21)}$$

From the foregoing analysis of U.S. average conditions, class C stability coefficients are the best first approximations to U.S. average conditions when $\sigma_y = \sigma_z$.

By letting D equal the distance to the occurrence of χ_{max} (see Tables H-2 and H-3),

$$\sigma_y = 0.209\ D^{0.9031} \qquad \text{(H-22)}$$

$$\sigma_z = 0.113\ D^{0.911} \qquad \text{(H-23)}$$

Thus, χ_{max} is determined as follows:

$$\chi_{max} = \frac{42.36\ Q}{\pi u D^{1.814}} \qquad \text{(H-24)}$$

It will be noted that Equations H-24 and H-20 are identical with the algebraic substitution of

$$h^2 = 0.01737\ D^{1.814} \qquad \text{(H-25)}$$

For U.S. average conditions u = 4.47 m/s so that Equation H-20 reduces to:

$$\chi_{max} = \frac{0.0524\ Q}{h^2} \qquad \text{(H-26)}$$

3. DEVELOPMENT OF MAXIMUM SOURCE SEVERITY

The general source severity, S, relationship has been defined as follows:

$$S = \frac{\bar{\chi}}{F} \qquad \text{(H-27)}$$

where $\bar{\chi}$ = mean ambient concentration
F = severity factor

a. Noncriteria Emissions

The value of $\bar{\chi}$ may be derived from χ_{max}, an undefined "short term" concentration. An approximation for longer term concentration may be made as follows (14):

For a 24 hour time period,

$$\bar{\chi}_1 = \chi_{max} \left(\frac{t_{max}}{t_L} \right)^{0.17} \quad \text{(H-28)}$$

or

$$\bar{\chi}_1 = \chi_{max} \left(\frac{3 \text{ min}}{1,440 \text{ min}} \right)^{0.17} \quad \text{(H-29)}$$

$$\bar{\chi}_1 = \chi_{max} \ (0.35) \quad \text{(H-30)}$$

Since the severity factor is defined and derived from TLV values as follows:

$$F = (TLV) \left(\frac{8}{24} \right) \left(\frac{1}{100} \right) \quad \text{(H-31)}$$

$$F = (3.33 \times 10^{-3}) \ TLV \quad \text{(H-32)}$$

then the severity factor, S, is defined as:

$$S = \frac{\bar{\chi}_1}{F} = \frac{(0.35)\chi_{max}}{(3.33 \times 10^{-3}) \ TLV} \quad \text{(H-33)}$$

$$S = \frac{105 \ \chi_{max}}{TLV} \quad \text{(H-34)}$$

If a weekly averaging period is used, then:

$$\bar{\chi}_2 = \chi_{max} \left(\frac{3}{10,080} \right)^{0.17} \quad \text{(H-35)}$$

or

$$\bar{\chi}_2 = (0.25)\chi_{max} \quad \text{(H-36)}$$

and

$$F = (TLV)\left(\frac{40}{168}\right)\left(\frac{1}{100}\right) \quad \text{(H-37)}$$

$$F = (2.38 \times 10^{-3})TLV \quad \text{(H-38)}$$

and the severity factor, S, is:

$$S = \frac{\bar{\chi}}{F^2} = \frac{(0.25)\chi_{max}}{(2.38 \times 10^{-3})\ TLV} \quad \text{(H-39)}$$

or

$$S = \frac{105\chi_{max}}{TLV} \quad \text{(H-40)}$$

which is entirely consistent, since the TLV is being corrected for a different exposure period.

Therefore, the severity can be derived from χ_{max} directly without regard to averaging time for non-criteria emissions. Thus, combining Equations H-40 and H-26, for elevated source, gives:

$$S = \frac{5.5\ Q}{TLV \cdot h^2} \quad \text{(H-41)}$$

b. Criteria Emissions

For the criteria pollutants, established standards may be used as F values in Equation H-27. These are given in Table H-4. However, Equation H-28 must be used to give the appropriate averaging period. These equations are developed for elevated sources using Equation H-26.

(1) CO Severity--
The primary standard for CO is reported for a 1-hr averaging time; therefore,

$$t_L = 60 \text{ min}$$

$$t_{max} = 3 \text{ min}$$

$$\bar{\chi}_{max} = \chi_{max}\left(\frac{3}{60}\right)^{0.17} \quad \text{(H-42)}$$

TABLE H-4. SUMMARY OF NATIONAL AMBIENT AIR QUALITY STANDARDS (33)

Pollutant	Averaging time	Primary standards	Secondary standards
Particulate matter	Annual (geometric mean)	75 $\mu g/m^3$	60[a] $\mu g/m^3$
	24-hour[b]	260 $\mu g/m^3$	160 $\mu g/m^3$
SO_x	Annual (arithmetic mean)	80 $\mu g/m^3$	t0 $\mu g/m^3$
	24-hour[b]	365 $\mu g/m^3$	260[c] $\mu g/m^3$
	3-hour[b]	-	1,300 $\mu g/m^3$
Carbon monoxide	8-hour[b]	10 mg/m^3	
	1-hour[b]	40,000 $\mu g/m^3$	(Same as primary)
Nitrogen dioxide	Annual (arithmetic mean)	100 $\mu g/m^3$	(Same as primary)
Photochemical oxidants	1-hour[b]	160 $\mu g/m^3$	(Same as primary)
Hydrocarbons (nonmethane)	3-hour (6 a.m. to 9 a.m.)	160 $\mu g/m^3$	(Same as primary)

[a] The secondary annual standard (60 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the 24-hour secondary standard.

[b] Not to be exceeded more than once per year.

[c] The secondary annual standard (260 $\mu g/m^3$) is a guide for assessing implementation plans to achieve the annual standard.

$$= \frac{2\,Q}{\pi e u h^2}\left(\frac{3}{60}\right)^{0.17} \qquad \text{(H-43)}$$

$$= \frac{2\,Q}{(3.14)(2.72)(4.5)\,h^2}\,(0.6) \qquad \text{(H-44)}$$

$$= \frac{0.052\,Q}{h^2}\,(0.6) \qquad \text{(H-45)}$$

$$\bar{\chi}_{max} = \frac{(3.12 \times 10^{-3})Q}{h^2} \qquad \text{(H-46)}$$

$$\text{Severity, S, } = \frac{\bar{\chi}_{max}}{F} \qquad \text{(H-47)}$$

Setting F equal to the primary standard for CO, i.e., 0.04 g/m^3 yields:

$$S = \frac{\bar{\chi}_{max}}{F} = \frac{(3.12 \times 10^{-2})Q}{0.04\,h^2} \qquad \text{(H-48)}$$

or

$$S_{CO} = \frac{0.78\,Q}{h^2} \qquad \text{(H-49)}$$

(33) Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 pp.

(2) Hydrocarbon Severity--
The primary standard for hydrocarbon is reported for a 3-hr averaging time.

$$t_L = 180 \text{ min}$$

$$t_{max} = 3 \text{ min}$$

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{3}{180}\right)^{0.17} \quad \text{(H-50)}$$

$$= 0.5\chi_{max} \quad \text{(H-51)}$$

$$= \frac{(0.5)(0.052)\ Q}{h^2} \quad \text{(H-52)}$$

$$\bar{\chi}_{max} = \frac{0.026\ Q}{h^2} \quad \text{(H-53)}$$

For hydrocarbons, $F = 1.6 \times 10^{-4}$ g/m^3

and

$$S = \frac{\bar{\chi}_{max}}{F} = \frac{0.026\ Q}{1.6 \times 10^{-4} h^2} \quad \text{(H-54)}$$

or

$$S_{HC} = \frac{162.5\ Q}{h^2} \quad \text{(H-55)}$$

(3) Particulate Severity--
The primary standard for particulate is reported for a 24-hr averaging time.

$$\bar{\chi}_{max} = \chi_{max} \left(\frac{3}{1,440}\right)^{0.17} \quad \text{(H-56)}$$

$$= \frac{(0.052)\ Q\ (0.35)}{h^2} \quad \text{(H-57)}$$

$$\bar{\chi}_{max} = \frac{(0.0182)\ Q}{h^2} \quad \text{(H-58)}$$

For particulates, $F = 2.6 \times 10^{-4}$ g/m^3

$$S = \frac{\bar{\chi}max}{F} = \frac{0.0182\ Q}{2.6 \times 10^{-4}\ h^2} \qquad \text{(H-59)}$$

$$S_P = \frac{70\ Q}{h^2} \qquad \text{(H-60)}$$

(4) SO_x Severity--
The primary standard for SO_x is reported for a 24-hr averaging time.

$$\bar{\chi}_{max} = \frac{(0.0182)\ Q}{h^2} \qquad \text{(H-61)}$$

The primary standard is 3.65×10^{-4} g/m^3

and

$$S = \frac{\bar{\chi}max}{F} = \frac{(0.0182)Q}{3.65 \times 10^{-4}\ h^2} \qquad \text{(H-62)}$$

or

$$S_{SO_x} = \frac{50\ Q}{h^2} \qquad \text{(H-63)}$$

(5) NO_x Severity--
Since NO_x has a primary standard with a 1-yr averaging time, the χmax correction equation cannot be used. As an alternative, the following equation was selected:

$$\bar{\chi} = \frac{2.03\ Q}{\sigma_z ux} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right] \qquad \text{(H-64)}$$

A difficulty arises, however, because a distance x, from emission point to receptor, is included and hence, the following rationale is used:

The equation $\chi_{max} = \frac{2\ Q}{\pi e u h^2}$

is valid for neutral conditions or when $\sigma_z \approx \sigma_y$. This maximum occurs when

$$h \approx \sqrt{2}\sigma_z$$

and since, under these conditions,

$$\sigma_z = ax^b$$

then the distance x_{max} where the maximum concentration occurs is:

$$x_{max} = \left(\frac{h}{\sqrt{2}a}\right)^{\frac{1}{b}}$$

For class C conditions,

$$a = 0.113$$
$$b = 0.911$$

Simplifying Equation H-64,

since $\sigma_z = 0.113\ x_{max}^{0.911}$

and $u = 4.5$ m/s

Letting $x = x_{max}$ in Equation H-64,

$$\bar{\chi} = \frac{4\ Q}{x_{max}^{1.911}} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right] \qquad \text{(H-65)}$$

$$x_{max} = \frac{h^{1.098}}{0.16} \qquad \text{(H-66)}$$

$$x_{max} = 7.5\ h^{1.098} \qquad \text{(H-67)}$$

and

$$\frac{4\ Q}{x_{max}^{1.911}} = \frac{4\ Q}{(7.5\ h^{1.098})^{1.911}} \qquad \text{(H-68)}$$

$$\bar{\chi} = \frac{0.085\ Q}{h^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{h}{\sigma_z}\right)^2\right] \qquad \text{(H-69)}$$

$$\sigma_z = 0.113x^{0.911} \qquad \text{(H-70)}$$

$$\sigma_z = 0.113\ (7.5\ h^{1.1})^{0.911} \qquad \text{(H-71)}$$

$$\sigma_z = 0.71\ h \qquad \text{(H-72)}$$

Therefore

$$\bar{\chi} = \frac{0.085\ Q}{h^{2.1}} \exp\left[-\frac{1}{2}\left(\frac{h}{0.71\ h}\right)^2\right] \qquad \text{(H-73)}$$

$$= \frac{0.085\ Q}{h^{2.1}}\ (0.371) \qquad \text{(H-74)}$$

$$\bar{\chi} = \frac{3.15 \times 10^{-2}\ Q}{h^{2.1}} \qquad \text{(H-75)}$$

Since the NO_x standard is 1.0×10^{-4} g/m^3, the NO_x severity equation is:

$$S_{NO_x} = \frac{(3.15 \times 10^{-2})\ Q}{1 \times 10^{-4}} \qquad \text{(H-76)}$$

$$S_{NO_x} = \frac{315\ Q}{h^{2.1}} \qquad \text{(H-77)}$$

GLOSSARY

active coal pile: aggregates of bituminous or subbituminous coal stored without any coating to prevent oxidation.

asphyxia: loss of consciousness as a result of too little oxygen and too much carbon dioxide in the blood.

atmospheric stability class: categories used to describe the turbulent structure and wind speed of the atmosphere.

avalanching: the continuous deposition and resuspension of loose soil particles blowing across a field.

background level: concentration of pollutants in the air prior to the addition of pollutants from the source of interest.

Brink samples: particle size distributed samples of particulate.

calibrating orifice assembly: a unit connected to the inlet of a high volume sampler for calibration.

catalytic reduction tube: a device used for conversion of carbon monoxide to methane via a nickel catalyst for detection by flame ionization chromatography.

chemical ionization mass spectroscopy: method of chemical analysis in which ions are passed in a vacuum first through an accelerating electric field and then through a strong magnetic field.

chromatographic column: long tube packed permeably with some absorbent for separating components of mixtures.

clump detachment: bulk dispersal of particle deposits from a dust pile in a wind tunnel.

coal tar derivatives: black, viscous liquids obtained from the destructive distillation of coal.

coal erodibility: capacity of coal for disintegration.

cohesive deposits: dust piles of coal with a particle size range of 6 μm to 8 μm.

composite TLV: threshold limit value of a compound based on the concentrations and threshold limit values of each of the elements.

confidence level: the probability that a random variable lies within a specified range given a known distribution of that variable.

confidence limits: upper and lower boundaries of values that a random variable lies between with a specific probability.

criteria pollutant: pollutant for which ambient air quality standards have been defined.

elevated sources: sources with a point of emission above ground level.

emission burden: ratio of emissions from a source to the total emissions per state or nation.

emission factor: emission rate divided by coal storage pile capacity.

entrainment rate: rate of material dispersal from a dust pile.

flame ionization detector: device which measures the electrical conductivity of a flame.

flame photmetric: emission of radiation (photons) by an element in a flame.

free-flowing deposits: dust beds containing particles in the size range of 100 μm to 150 μm.

gross particulate: the entire quantity of respirable particulates considered as inert, nuisance particulates.

hazard factor: toxicity of a pollutant corrected for a 24 hr exposure with a safety factor of 100.

impact factor: a factor which shows the relative environmental impact of emission sources for use in assigning priorities in investigative work.

implementation plans: procedures for achieving ambient air quality standards.

inactive coal pile: coal stockpile coated with a tar derivative to prevent oxidation.

insolation class: a categorization for various levels of incoming solar radiation.

mass coal dust: respirable suspended particulate which is found in coal mines, as differentiated from ambient particulate matter.

noncriteria pollutants: pollutants for which ambient air quality standards have not been established.

Nucleopore: a polycarbonate filter medium.

open sources: fugitive sources which do not have a definable point of emission such as a stack or vent.

pneumoconiosis: any of various diseased conditions of the lung characterized by fibrous hardening as a result of chronic inhalation of irritating dust particles.

quartz: a brilliant, crystalline mineral as silicon dioxide.

radiation index: a reference to the amount of incoming sun rays that strike the earth's surface.

respirable range: all of those particulates less than 7 μm in diameter.

sensitivity analysis: mathematical technique in which the effect of one parameter is observed over a range of possible values while the remaining parameters are kept constant.

spectrographic analysis: study of the dispersal of light into a spectrum passing through a medium.

stripper column: a column in series with the analytical column which H_2O, CO_2, and hydrocarbons (ex. CH_4) are removed.

Thornthwaite's P-E index: a relationship expressing the amount of precipitation and the mean temperature in a given region.

weathering: erosive effects of the forces of weather on a coal pile.

x-ray fluorescence: analytical technique in which x-rays are absorbed depending upon the wavelength and the material.